BRICK PAVEMENTS

WESTERN PAVING BRICK
MANUFACTURERS ASSOCIATION
1917

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Text Book on Brick Pavements

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416 Dwight Building, Kansas City, Missouri

Announcement

IN ISSUING this volume, the Western Paving Brick Manufacturers Association is pursuing one of the chief aims of its organization—the education of the public in the characteristics and proper construction of Vitrified Brick Highways and City Pavements.

This Association endeavors to bring about a closer relationship between the public, or the user, and the manufacturer, realizing a satisfied public means securing increased business.

It is believed the circulation of an authorative Text Book written by an Engineer of prominence, will do much toward improving the quality and construction of Vitrified Brick Highways and City Pavements, create a greater interest and demand for this type of improvement, and establish additional confidence of the public.

With this sole purpose in view, the Association commends this Text Book to those who are interested in permanent pavements.

WESTERN PAVING BRICK
MANUFACTURERS ASSOCIATION,

G. W. Thurston, Secretary,
416 Dwight Building,
Kansas City, Missouri.

Brick pavement in Holland over 100 years old.

A TEXT BOOK

ON

BRICK PAVEMENTS

BY

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WESTERN PAVING BRICK MANUFACTURERS
ASSOCIATION

KANSAS CITY, MISSOURI.

1917

PREFACE

HIGHWAY ECONOMICS have advanced so rapidly in the past fifteen years that it has become practically impossible to treat fully all phases of the subject in one volume. A book on street pavements alone becomes bulky and special volumes are necessary to cover the subjects of street designs, country roads, street cleaning, etc. The increased amount of traffic due to the rapid development of the automobile has not only thrown an increased strain on street and road pavements, but has created a demand for more pavements and for smoother and better pavements maintained to a high degree of perfection.

It occured to the writer that a series of hand books treating each of the standard pavements separately would perhaps enable them to be covered in a comprehensive manner with the entire emphasis of the subject matter on the particular pavement under consideration. In this way each class of pavement and related subjects may be treated in an exhaustive manner with the view to obtaining the most satisfactory final pavement surface of the type under discussion. There must of necessity be included considerable matter applicable to all the standard pavements but an effort has been made to exclude from this volume general discussions which are not pertinent to brick pavements.

The author is an advocate of good, well constructed pavements. He believes that there is a place for all the standard paving materials, provided that skill and care are used in the design and construction. Greater attention to details and a more thorough understanding of the limitations as well as the strong points of each kind of pavement are essential items to good street or road surfaces.

It is hoped that the present volume on Brick Pavements will prove of interest to municipal officers, commissioners and citizens in general as well as to city engineers, road engineers, county surveyors and paving contractors. For this reason many tables, formulae and other technical matter have been omitted as these would be dry reading for the first class of readers and are available to the second class in numerous published handbooks for engineers.

The author wishes to acknowledge the help and encouragement rendered by the Western Paving Brick Manufacturers Association in the preparation of this volume. They have undertaken its publication and distribution and otherwise aided in gathering the illustrations and historical data. Their interest in the subject matter has been the presentation of methods of construction which will insure the best and most satisfactory use of brick material for pavements.

August, 1916 CLARK R. MANDIGO.
Kansas City, Missouri.

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CHAPTER I

BRICK PAVEMENTS

ROADS OF SOME KIND are essential to civilization and hard surface roads are a necessity in the up-building of the commercial and social features of a progressing community. It has been well said that roads are the physical system by which to measure the progress of an age or a people. Roads are so important to the life of a community that they are usually the first things thought of in any new colony. First there is the trail, then the path, the road, the graded earth road and finally the paved road; each one representing a step of progress and making possible larger centers of population and greater social and commercial activity.

While the remarkable growth of the steam railroad in the United States and the sparse population of the farm land has lessened the importance of a comprehensive system of cross country paved roads, the local roads as feeders for commercial towns and railroads, are as important as formerly. It is manifestly impossible to construct a railway to every farm. Pavements are desirable at any time and become a necessity when any great number of wheel vehicles attempt to use the roads.

The Egyptians constructed paved roads for their use in building the Pyramids as long ago as 6000 B. C. The Carthagenians built a system of military roads which very nearly caused the downfall of Rome. The Romans, having learned their lesson, built a remarkable system of paved highways reaching all parts of their Empire and some of their pavements stand today as a monument to their thoroughness of construction. The Roman roads were the most substantial structures of the kind ever laid and were practically solid masonry three or four feet thick. The surface consisted of large flat blocks of stone imbedded in mortar. The Appian Way built about 300 B. C. is said to have been in condition for travel 800 years after its construction, but the difference in the character and amount of traffic must be considered in comparing this with any modern construction. The streets of ancient Rome, Pompeii, Jerusalem, Athens and other cities were paved. In fact wherever civilization reached a high state of development in ancient times, we find paved streets and roads.

In modern times, however, it was not until the 16th Century that any attempt was made to improve the roads of France or England. Paris had a population of probably 200,000 before its first pavements were built in 1184. The first regular pavement was laid in London about 1533, but square Granite Blocks were not introduced until as late as 1760. The surfacing of the streets in European cities in early times however should hardly be dignified by the name of pavement; being nothing more than field stones tamped into the mud. Even with the light traffic of those days, their construction and drainage were so poor that their condition soon became detestable. It is related that the coachmen of the nobles took great delight in driving into the holes even at the risk of upsetting the carriage in order to witness the discomfiture of the unwary pedestrian who

was splashed from head to foot with filthy mud. Late in the 18th Century systematic and scientific construction of pavements began and we have such names as Tresaguet, a French Engineer, and Telford and Macadam, Englishmen, whose influence on road construction has been felt down to the present time. Not only was the initial cost lessened and a better surface obtained by these engineers, but the maintenance cost was very much reduced. Brick, Stone Block,

Fig. 1—A Vertical Fiber Brick Highway in Calcasieu Parish, Louisiana.

and Wood pavements came into use at about the same time with the awakening of the civic consciousness of the cities.

Having realized the necessity of less haphazard and more careful construction, the development of road and street pavement progressed fairly rapidly, although it was not until 1872 that the first concrete base for paving was laid in London.

In the United States street surfacing followed much the same course as in England. Although the first pavement of cobble-stone was laid in New York in 1656, it was almost the only kind used until

1849, while the concrete base was not introduced until as late as 1880. The highways of the United States were not improved at the same rate and are at present but incompletely and poorly developed. This has been due mainly to the sparse settlement of the country and to the excellence of the railway systems, but nearly as much blame can be laid to our system of administration, which has been indifferent and has not given the proper support to the skillful road engineer.

The public lack appreciation of the benefits derived from paved roads and are still inclined to believe that all material is alike or that anyone can build a road. The main roads should be planned and carried out as a national policy instead of being left to the various States, Counties or Townships, which are manifestly incapable of developing a co-ordinated national road system.

A list of the various materials experimented with for paving surfaces apparently includes everything that could conceivably be used for this purpose. The materials have also been laid in all manner of ways and combinations. An iron pavement was laid in New York of block form roughened on the surface. It was so noisy and caused so much damage to horses, which tore off their shoes, slipped and fell frequently, that it was taken up after a short trial. Various forms of Iron and Concrete, Iron Ore, Artificial Stone Blocks, divitrified Glass, compressed Marsh Grass, or Wood Pulp, by-products of sugar refineries and so on, have all been experimented with, while the combinations that have been tried with wood and with asphalt are almost without number. All of these experiments cannot be called failures, but nearly all have proven impractical for one reason or another, and have never been used except for short stretches. It is interesting to note that the paving materials being used now are the ones in use in the early days of the paving industry and that the pavements which are with-standing modern traffic and modern street and road conditions today are direct descendents of the pavements of forty years ago. A gradual improvement in methods of manufacturing and laying, as machinery and a better understanding of the material developed, has taken place and can be traced step by step down to the present. Even with the standard materials, there have been many failures of pavements, mainly due to a lack of appreciation of the characteristics of the material used or a disregard of accepted Engineering design. Generally speaking, however, constant progress has been made and the pavements of today are as a rule many times better than those of forty or even twenty years ago.

In no case has this progressive improvement been more marked or taken along surer lines than in brick paving. Brick pavements have been used in the Netherlands for nearly two centuries, and some of them which are over fifty years old are still in fair condition. Byrne says the old brick pavements in the Hague, Holland, are laid of hard burned brick about 8½ inches long, 4¼ inches wide and 2⅛ inches deep and are laid with the joints as close as possible. Amsterdam is paved almost entirely with brick as are also a number of roads throughout the country. The commercial city and seaport Rotterdam, with its warehouse and dock

Fig. 2—Brick on Business Street, Wichita, Kansas, 23 Years Old.

traffic, has used brick successfully for many years. The early pavements were laid on sand, but later a hydraulic-cement was used with the sand to form the base and the bricks laid on this. This was before the time of concrete bases. Brick pavement has also been used in Japan since very ancient times, but was very crudely built. Other countries have used brick to more or less extent, but in the United States it has reached its greatest perfection.

It was not until about 1870 that the first brick pavement was laid in the United States at Charleston, West Virginia. It is said that this pavement was laid by a private citizen at his own expense in spite of the ridicule of his neighbors. Two or three years later, the city laid a stretch of brick pavement which was in good condition in 1900 and had received very little repairs.

Bloomington, Illinois, laid its first brick pavement in 1875, and a great many small cities throughout the central west began the use of brick in the 80's. The first large city to lay brick pavement was Philadelphia in 1887 and it has laid a continually increasing amount on account of its popularity until there is at present a very large mileage of brick in use there.

Cleveland, Ohio, began laying brick in 1889 and in 1913 had over 328 miles of brick streets. A large majority of the pavement in Cleveland was laid on a sand foundation, and on this account some of it has required relaying in less than 15 years, although much of it over 20 years old is still in use.

The first brick pavement in Chicago, Illinois, was laid on Lake Avenue from 35th Street to 37th Street in 1893, and was still in use after seventeen years of heavy traffic, although badly worn. This was a two course brick pavement.

Kansas City, Missouri, began using brick for paving about 1890 and has over 850,000 square yards of it in use at present on streets alone. Of this total over 493,000 square yards is over ten years old, of which 439,000 square yards has seen fifteen years or more of service. There were over 132,400 square yards in use in 1916, which had been down and in use 20 years or more. The oldest brick pavements in Kansas City are 25 years old. These brick paved streets which have seen ten years or more service include wholesale and retail business, street car line streets and residence streets scattered throughout the older, built-up part of the city. In fact some of the oldest brick pavements are on streets in or near the business section and have always received a very considerable amount of traffic. Less than 30% of these streets have ever received any repairs due to wear and these repairs have generally been of an inexpensive and minor character. Thirteenth Street from Oak to Woodland, which is close to the business section of the City, receives considerable traffic and was laid in 1894. The joints were filled with sand and the bricks are consequently rounded on top. There are some places at the intersections which need repairs, but the pavement as a whole is in good condition and will probably give a number of additional years service. Tenth Street from Central to Wyandotte was paved with brick in 1892, and has been repaired once by raising some sunken places and turning the brick. It was in fair condition in 1916. No other kind of pavement in Kansas City can show as long life or as low maintenance cost as brick. The brick pavements laid in recent years are giving good satisfaction and

Fig. 3—Brick on Business Street, Kansas City, Mo., 24 Years Old.

from present indications should beat the records of their predecessors.

Where the use of brick has been once commenced in the improvement of country roads, the community has been so well satisfied that it has been adopted for the main traveled roads and is often the only material used in some towns.

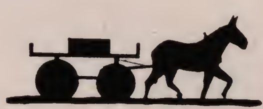
To take two examples: Cuyahoga County, Ohio, had over 400 miles of brick roads in 1913, and King County, Washington, recently laid over 18 miles of brick on the mountainous roads outside of Seattle.

When the inadequate foundations, the quality of the brick and the method of laying are all considered, it is somewhat surprising that the earlier brick pavements have been so successful and have had such an exceptionally long life. It has awakened the brick manufacturers and highway engineers to the possibilities of this material to such an extent that the value of paving brick manufactured in the United States has rapidly increased until it now represents one of the important industries. At first there was little discrimination in the kind of brick used and even the best quality brick laid in the early days would not now be considered suitable for paving. To most people at that time and to some even now a brick was a brick without regard to its manufacture. Few or no tests were required to determine the suitableness or wearing qualities of the various brands of brick, with the result that some poor pavement was laid.

Inexperience in designing and laying is also responsible for many of the defects in the older brick pavements. It is unfortunately an easy matter in this country to cite numerous examples of failure or defects in any kind of paving material. This is an indictment against the American method of hasty, careless, temporary construction as opposed to the thoroughness, thoughtfulness and permanence demanded by good paving. Invariably where reported failures in brick pavement have been investigated, it has been found that poor material, poor design or poor workmanship is responsible, all of which could have been avoided. If public officials could be made to see the ultimate economy in the employment of a capable, experienced highway engineer and would use some care and determination in the selection of the manufacturer who furnishes the material and the contractor who constructs the pavement, even if the first cost is a little more, then years would be added to the life of our pavements and the public will have increased satisfaction in their use.

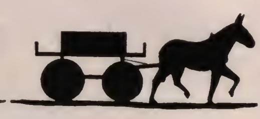
Brick paving has been developed to a high state of perfection. The method of manufacture and of laying has been standardized to a great extent, and with experienced and conscientious inspection, its satisfaction and behavior can be foretold with a great degree of certainty. The brick material may be had in small units of practically uniform size, in large or small quantities, and of uniform quality. It is nearly non-absorbent, has more than sufficient strength to with-stand the heaviest wheel and toe-calk loads of modern traffic and is unaffected by water, frost, weathering or age. Vitrified clay is more permanent than some granites in this last named respect.

Brick pavement offers as low tractive resistance at all seasons of the year as any paving material. If one horse can just draw a given load along a level brick road, it will take 1¼ to 1½ horses to draw the same load on a sheet asphalt surface, depending on the season of the year; 2 horses for granite block, 3 horses on macadam,



Sandy Road

Good Earth



Macadam

5 horses to draw the same load on a good earth road, 20 horses on a sandy road or 30 horses through deep sand, all of the pavements to be assumed dry and in good condition. This illustrates better than anything else the part that tractive resistance plays. The computation is based on a large number of experiments performed by the United States Government, and by private investigators, both here and abroad.

Although brick pavement has a pleasing smoothness, it affords a good foothold for horses and possesses adequate frictional properties for rubber tired vehicles regardless of weather conditions. Brick can therefore be used, when proper methods of construction are employed, on all grades with safety. It does not wear slippery but increases in serviceability with age.

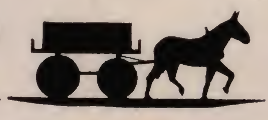
Brick pavement can also be laid at a reasonable first cost, and on account of its durability and low maintenance cost, it has a very low cost per year distributed over a term of years. Pavements should be treated as an investment and so designed and constructed that each dollar of investment will return the greatest amount of service.

Even with the early brick surfaces the life has averaged over fifteen years and with modern construction it will undoubtedly be much greater. Public officials are possessed with the laudable desire to make as big a showing with the money at their command as possible, but this should not be carried to such an extent as to lose sight of the principles of suitableness or serviceability. They do not do this in their own affairs and should therefore invest public money in such a way as to get the greatest return. Brick paving has a well deserved reputation for the lowest annual repair cost of any pavement, except granite block. Brick pavement may be expeditiously laid, requires no expensive contractors outfit or especially expert labor, so that the fullest competition in letting the contract may be obtained.

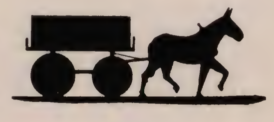
It is a comparatively easy matter to repair service cuts which may be necessary after the pavement is laid, and should defects in the surface occur, the repairs are easily and quickly made with a small force and no special equipment. This is of importance to those in charge of country roads or streets in towns or small cities.

Pavements which require expensive plant equipment for laying or technical specialists to see that the specifications are being complied with, place the authorities at a disadvantage and may also prevent the fullest competition among paving contractors. It soon becomes a serious proposition to properly maintain such pavements without

Granite Block



Sheet Asphalt



Brick

engaging a chemist and investing in proper and expensive equipment.

Brick pavement is unaffected by weathering, by water or by mud on the surface and does not itself produce mud or dust. It is easily cleaned either by flushing, sweeping or machine brooms. It also has a clean, fresh appearance and being non-absorbent it is also sanitary.

When properly laid it is not noisy, gives an excellent riding surface for all classes of vehicles, and presents a pleasing appearance.

With recent developments in brick manufacture and methods of laying, brick pavement can be designed to economically take care of the light traffic of a country road or the heaviest traffic of a city street, to give a sanitary, quiet, easy riding surface for a residence street, or a cheap, dustless, durable, low maintenance pavement for the business section. It is no longer necessary to use the same depth of brick surfacing or lay it the same on a country road as around a city warehouse. Engineers should familiarize themselves with these improvements and use the type of construction economically suitable and possessing the qualities which it is desirable to emphasize, depending on the use of the street to be paved. The various types of brick pavement and their characteristics will be discussed in later chapters.

Brick pavement has established itself as a standard pavement of the highest quality through a long period of exceptional durability and service in all parts of the country. It can be designed to take care of all conditions of modern traffic at a reasonable first cost with a very low yearly maintenance cost. It can be laid and repaired without large plant equipment. It does not deteriorate with age and is not noisy. While possessing a pleasing appearance and an easy riding smoothness, it affords a good foothold for horses and all classes of vehicles and is capable of withstanding the shock and abrasion of the heaviest traffic.

Brick pavement offers a low tractive resistance and is especially favorable to all classes of traffic; being non-absorbent, non-dust or mud producing, and easily and effectively cleaned, it is sanitary. A properly constructed brick pavement is an ideal pavement in all respects.

CHAPTER II

HIGHWAY ECONOMICS

THE TERM, HIGHWAY, is used to designate any public thoroughfare or line of communication whether in the country, town or city—whether a road, a boulevard, a street or an alley. The highway takes account of the entire width of the street or road, including sidewalks and the tree planting space, while carriageway or roadway refers more specifically to the paved or traveled portion of the highway. Economics is the science of the careful, judicious use or management of a thing. In studying the science of the judicious use of public thoroughfares, the question naturally rises as to what returns may be expected from improved roads and streets. Do the advantages gained by paved roadways warrant the expenditure of the money necessary for their proper construction? Recognizing that certain circumstances may alter cases, all students of highway economics agree that in the large majority of cases in the United States, improvement of roads is worth much more than the cost.

There is no record that any community has ever regretted the improvement of its public thoroughfares and it invariably happens that once started, construction work is carried on as fast as finances will permit. It is like the claim made for a certain confection, the more improved highways a community has, the more it finds it needs and wants. This is the history of street and road improvement in every locality.

The advantages to be gained through paved roads by the farmers and by the residents of small towns are in many ways so obvious that it seems scarcely necessary to call attention to any but the most important cases.

An improved road reduces the cost of hauling very materially. This reduction does not always appeal to the farmer who does his own teaming, because his cost is indirect and is paid for by the time and labor of himself and his horses. It is sometimes brought home to him forcibly, however, when he meets a friend in town who lives on a hard surfaced road and has from three to ten times the load behind his team that he himself has been able to haul over a dirt road. Considering the time of a farmer and his team as worth something, estimates have been made of the cost of hauling farm produce which run into the hundreds of million dollars. It is impossible, however, to determine with any degree of accuracy the saving in cost of hauling effected by paved roads. That hard surfaced roads do reduce the cost is evidenced by the fact that farm land served by them commands a higher price than just as good land the same distance from the market, but on a dirt road. At average prices for labor and teams and with full loads on level roads the cost of hauling one ton, one mile may run over 60 cents on dry sand, 40 cents on a fairly good but muddy road, to as low as 10 or 12 cents on an earth road in dry, good condition; while on a level brick pavement the cost varies from 2 to 5 cents per ton mile, depending on its condition. On this basis an enormous saving is obtained by paved

roadways. This may be compared with railroad transportation which is carried on at a cost of about ½ cent per ton mile. It is also well to compare the attention given to railways in order to reduce their cost of transportation with the amount of maintenance given the average road.

Practically all merchandise and produce must at one time or another in its journey from producer to consumer be hauled over highways, some of it several times. The wheat must be hauled to

Fig. 5—A Vitrified Brick Road, St. Louis County, Missouri.

the railroad or mill and the flour is usually delivered over pavements to the consumer. The cotton may make several trips over roads on its way from plantation to the shirt on your back. The highways of the country are the feeders and the ultimate distributors for the railroads. While we are astounded at the magnitude of the freight tonnage hauled by the railroads, we fail to realize the equally enormous traffic of our city and country highways. This traffic is widely distributed, is in small units, and the amount done by any one individual is only a minute part of the total. The small economic gain of the individual, however, makes the economic prosperity of the community,

and the community which reduces the cost and facilitates the collection of those things it has to sell and the distribution of those things it must buy is bound to forge ahead. While railway corporations are watching the hundredth of a cent variation in their ton mile cost of transportation, are we not overlooking a great opportunity in failing to improve our roads and streets with easy grades and durable pavements, and so reduce the cost of transportation over them from five to ten times?

The most tangible benefit of a hard surfaced road to the agriculturist is that, if it is constructed of proper materials, it is serviceable the year around, in all seasons and under all conditions of weather. The road is always ready to transport the maximum load. This fact is of great advantage to the farmer, both as a matter of convenience and for financial reasons. He immediately has the power to market his crops under the most favorable market conditions and is not obliged to sell them during the most favorable local weather condition. He has a wider choice of the time of marketing and by taking advantage of favorable price conditions, he may often realize a considerable additional profit on his produce. His market radius is also enlarged. If the nearest buyer offers less than one a little further away, he can afford to make the additional haul over the paved road in order to avail himself of the better price. This argument of course, applies with equal force to the purchase of supplies by the farmer. Owing to the greater speed and ease of traveling, he can take advantage of the competition among merchants, and without regard to weather conditions, often when work on the farm is tied up because of bad weather, he can sell where the highest prices prevail and buy where values are the cheapest.

The 365-day road also enables the land owner to cultivate crops otherwise not marketable. The dairy and poultry products, fruit and fresh vegetables, require marketing when they are mature in order to realize the best prices. Even if there are not many days when the dirt road is absolutely impassable, these days may occur at a time when a crop of perishable produce is ripe and cause a total loss. Some farm produce requires daily marketing and a farm on a dirt road cannot undertake to raise this class of produce profitably unless very close to the market.

Where all season roads have been constructed near our cities daily hauls by auto truck of from 25 to 50 miles are not at all uncommon, so that the outlying farmer may market his fresh vegetables and dairy products to advantage. In fact transportation by automobile, of which so much in the way of market radius and saving in cost and time is being accomplished, depends primarily for its success on smooth, durable, paved roadways.

These advantages accrue in other ways to the towns and cities served by paved roads. By making travel easier and independent of the season of the year, they materially widen the radius of the commercial town and equalize the mercantile business from week to week. The land owners, being more prosperous, are induced to come to town more frequently and buy more liberally.

Good roads also induce tourist travel and vacation residents who are a source of legitimate profit to the community. Switzerland is maintained almost entirely by the revenue derived from tourists. The rapid increase in automobile tourist travel is due to the increased mileage of paved roads and while the automobilist clamors for more and takes pleasure out of those already built, the real financial benefit comes to the community which encourages his visits.

Fig. 6—A Vitrified Brick Road Near Wichita, Kansas.

The pleasure tourist usually spends considerable money and takes nothing away with him.

With the automobile, such a factor in quick, convenient transportation over hard surfaced roads, rural land for some distance from towns and cities becomes suburban land for workers in the City who enjoy and can afford the country life, making a consequent increase in the value of land. Good roads by making land more available at all seasons of the year, increase the possible number of buyers, and the land owner receives a better price if he sells. Or on a forced sale the land will bring more nearly what it is worth as it has a better market.

An intangible advantage of all-season paved roads and yet a very real one, is the promotion of social intercourse between both the landholders themselves, and between the residents of the towns and the farmers. The privilege or opportunity of visiting ones neighbors, or attending social gatherings, lectures, churches, or theatres, with ease and comfort, adds much to the pleasures of country life. With the extension of the rural free mail and parcel post delivery and the increased use of the automobile for getting about, the success of both of which depends on having 365-day roads, life in the country has been much enriched and benefited. The self-respect of the farmers has been stimulated and broken down fences have been repaired. shrubs trimmed, and the general comfort and appearance of the farm house improved. With paved roads it has been possible to consolidate the rural schools, so that more competent teachers can be employed and more extended and broader education offered to the children. In many places these rural school houses have become the social centers for a large number of families and are used to the help and pleasure of the older as well as the younger members.

All of these advantages—what may be termed the durable satisfactions of life; the things that make life worth living, can only be successfully enjoyed to their full extent by sections which have smooth, well constructed paved roads, ready for use every day in the year.

The advantages of paved roads may therefore be sumed up in two classes; as the tangible, money-saving benefits, due; (1) to the reduced cost of hauling; (2) to being able to market crops at the most favorable prices; (3) to a wider choice of market; (4) to a wider choice of the time of marketing; (5) to being able to cultivate more diversified crops; (6) to making possible the use of auto-transportation; (7) to a wider radius of the commercial town; (8) to equalizing the mercantile business of the town merchants; (9) to the encouragement of tourist travel; (10) to the changing of rural land to suburban property; (11) to a wider market for the land itself and its greater salable value; and the intangible benefits due: (1) to the much improved facility for social intercourse; (2) to the rural mail delivery extension; (3) to the consolidation of rural schools; (4) to the pleasure and recreation in driving; (5) to the mental stimulation of the people living on an improved highway. If these benefits are not forthcoming it is because the people have not made the fullest use of a properly constructed road.

The value of an economical, durable, pavement on the streets of our towns and cities is somewhat similar to the country road since paved streets promote the social, financial, and educational well-being of the residents. Paved streets reduce the cost of transportation and establish a permanent grade for the further development of the street and the buildings on the adjoining property. Numerous paved streets in a town increase the facilities for fire protection. The proportion of miles of pavement to the miles of all streets is one of the things always reported by the fire insurance rate adjustors. Pavements materially improve the appearance and beauty of business as well as residence streets. A well drained, impervious, smooth, dustless pavement, adds to the cleanliness of the homes of the residents along the street, and by the elimination of mud and stagnant pools in wet weather, and dust in dry weather, the street ceases to be a breeder

for disease germs and for mosquitoes and flies which carry disease. A paved street is a sanitary measure of fundamental importance. The paving of the streets of the cities of Cuba and Panama was one of the things first demanded by the American sanitary experts in their

Fig. 7—An Unpaved Street is Frequently a Sorry Sight.

fight against squalor, filth, and fever. It is interesting to note in passing that brick shipped from the United States was the paving material selected for Panama, although other paving materials nearer at hand were cheaper.

Well paved streets promote social intercourse and pleasure driving; a most delightful form of recreation. It is a well known fact that paving increases the value of abutting property to a greater amount than the cost of the paving itself. This is recognized by real estate dealers, who invariably pave the streets of their additions, if they can obtain the capital necessary, before placing the property on the market. Loans on property facing a well paved street can usually be obtained at a lower rate of interest than equally as good property on an unpaved street. This is because investors realize that property on a paved street can be more easily disposed of and to better advantage on a quick sale. It is more desirable and commands the attention of a large number of buyers. Pavement is in reality an investment in the improvement of the abutting property as much as any building erected on the property itself, and like the building, if constructed of proper materials and in a proper manner, it will return good interest on the investment. Paved city streets, therefore bring the following benefits:

1. A lowered cost of transportation.

2. The establishment of a permanent grade.

3. Sanitary and healthful street conditions.

4. Cleaner homes and places of business.

5. Greater comfort and better living conditions.

6. Improvement in the beauty and appearance of both residence and business streets.

7. Increased facility for social intercourse and pleasure driving.

8. Increased fire protection with consequent lower insurance rates.

9. Increase in the value of the abutting land, part of which is a measure of the above benefits.

10. Increased desirability of the abutting property with lower rate of interest on loans and a greater number of buyers available for quick sale.

It is important to keep these objects and benefits of paved roads and streets in mind in laying out, grading and constructing them, so that the fullest realization of these benefits may accrue to the community.

The proper location, grade, and wearing surface of a street or road are the most important factors in the attainment of these advantages. The location and grade, however, involve so many things peculiar to a given locality or section of the country, that only a few of the general principles regarding safe and cheap transportation can be given.

The force necessary to haul a loaded vehicle is consumed (1) by axle friction, (2) by air resistance, (3) by grade resistance, and (4)

by rolling resistance. The first three are independent of the road surface and depend on the construction of the vehicle, the speed at which it travels and the force of gravity. The rolling resistance depends somewhat on the diameter of the wheels and the width of the tires, but more especially on the surface supporting the vehicle. It

Fig. 8—A Vitrified Vertical Fiber Brick Paved Street Has an Air of Cleanliness and Respectability.

is the greatest factor in determining the power required to move a given load on a level road. The United States Department of Agriculture has determined that a horse and an ordinary wagon will haul the following loads over level roads; muddy earth, from nothing to 800 pounds; smooth dry earth, 1,000 to 2,000 pounds; poor gravel roads, from 1,000 to 1,500 pounds; good gravel, 3,300 pounds; rock or macadam, from 2,000 to 5,000 pounds, and brick,

from 5,000 to 8,000 pounds. Since all factors of load resistance were the same in these experiments, except the road surface itself, the great difference in tractive resistance of various surfaces is apparent. It has been determined that a horse can exert a pull of one-tenth its weight, at a walk, continuously during a ten hour work day, six days a week, and the maximum pull which can be exerted is about one-half of its weight for short distances only. On grades of a few hundred feet it may be assumed that a horse can exert a pull of one quarter of its weight. Now the resistance of a load on an incline due to gravity, that is the grade resistance, can be shown to be approximately 20 pounds per ton multiplied by the per cent of grade. By exerting a pull of one-tenth of its weight, a 1,200 pound horse can haul 4 tons on a level brick road in fair condition; the tractive resistance being 30 pounds per ton. The grade resistance for this load is 4 tons, the load, plus 0.6 tons, the weight of the horse multiplied by 20, or 92 pounds for each per cent of grade. The horse can exert a pull for a short time of one-fourth its weight or 300 pounds, of which 120 pounds is used to overcome tractive resistance and the balance, or 180 pounds, is used to overcome grade resistance at the rate of 92 pounds for each per cent or a maximum allowable grade of about 2 per cent. On a dry, packed earth road, where the tractive resistance is 100 pounds per ton the maximum load hauled on the level is reduced to 1.2 tons and the grade resistance for this load, including the weight of the horse, is 36 pounds for each per cent of grade. The surplus power of the horse, or 180 pounds, will therefore haul the load up a 5 per cent grade of short length. These examples are cited to show the great importance in maintaining a low grade on improved highways. The force of gravity acts alike on loads of the same amount independent of the surface they are hauled over, and it is therefore a greater proportion of the total rolling resistance the less the tractive resistance or the better the road surface and the greater the load. A horse would of course haul a greater load up a 5 per cent grade paved with brick than up the same grade on an earth road, but in order to take the fullest advantage of the low tractive resistance of brick pavement, the grades should be so low as not to be the factor limiting the loads.

In hilly country 2% grades are often impractical. The maximum grades on the main thoroughfares should not, however, exceed 5% or possibly 6% even in mountainous country. Every effort should be made by economical and careful engineering to reduce this maximum to as low a point as possible, and especially to see that the maximum grade between any two centers of population, the ruling grade it is called, is not much greater than the average run of grades between these points. The maximum or ruling grade should be reduced as low as practical and all grades should be made as short as possible. While a horse may exert two and one-half times its normal pull, this extra effort cannot be sustained for long periods or frequently repeated without exhausting the horse before the days work is finished.

What has been said regarding the effect of tractive and grade resistance on horse drawn vehicles, is equally true in its general application to self-propelled vehicles. Although the automobile and auto-truck must be reckoned with in highway design, horses are still a big factor and for some pavements like brick, conditions are

not much changed by the growth of automobile transportation. The automobile has a much greater reserve power than the horse and of course can be made to surmount comparatively heavy grades with the maximum load. This is done at a sacrifice of speed wherein one of the chief advantages of the auto lies and with increased consumption

Fig. 9—Roanoke Traffic Way, Kansas City, Mo., Brick Road Curved to Get Good Grade at Less Cost.

of fuel and wear and tear on the machine. It is unfortunate that no reliable data regarding the effect of grade resistance on automobiles is available, but it is well known that the frequent use of the reserve power—"Low speed"—increases the gasoline consumption and the wear and tear on the machinery out of all proportion to the distance traveled. The grade resistance, itself, is the same for a given load regardless

of the motive power and the percentage of grade should, therefore, be kept at a minimum.

It is a noteworthy fact that most of the excessive grades on our highways could have been overcome or avoided without extraordinary expense. Too much stress has been laid on the straight line road; the saving in distance at a sacrifice of grade has been much overestimated. For example the actual distance over a hill may be no less than the distance around the hill; the road in one case being curved in a vertical plane, in the other case in a horizontal plane. In fact it is surprising to find by actual measurement how little is added to the length of a road by slight deviations from a straight line. Even where the straight road is shorter, the cost of construction is frequently much greater than for a road deviating enough to avoid the natural obstacles.

The economical location of a road demands that the interest on the cost of construction, the annual cost of maintenance and the cost of conducting transportation over it, taken together, shall be a minimum, and all of these factors should be studied before deciding on any changes. The section line system of roads which is common in the West, though convenient in many ways, often makes proper road location in rough country a difficult matter. Where new rights-of-way cannot be exchanged for the old, it may be economy to condemn a road in the new location as the money so spent may often be saved many times over in the cost of construction. It is also a great advantage to supplement the rectangular road system by diagonal highways connecting the commercial centers by the shortest routes consistent with good grades.

The location of the main traveled roads and the fixing of the grades on the same is a delicate and painstaking operation, calling for much skill and study. Highway Engineers would do well to study the theory of location of railroads and learn to take advantage of the natural typography of the ground.

The following principles may be used as a guide in the final selection of the location:

1. Follow the route giving the easiest grade, remembering that the greater the expected travel and the better the pavement to be used, the more essential is a low grade.

2. Connect places of importance by the shortest and most direct route commensurate with low grades.

3. Avoid all unnecessary ascents and descents.

4. Cross ridges at lowest points and valleys at highest points possible.

5. Avoid obstacles requiring expensive construction, but where streams, etc. are encountered cross them at right angles in order to reduce the cost of structural work.

6. Avoid grade crossings of railways.

7. Locate the center line with reference to the natural surface in order to make the grading and drainage cost as cheap as possible.

8. Avoid sharp turns or turns where the view of the road each side of the turn is obstructed.

In fixing the grades on the road the following fundamentals should be kept in mind:

1. Make maximum grades as short and infrequent as possible.

2. Provide a grade for longitudinal drainage on flat stretches of at least one-half of one per cent, or provide sufficient capacity and fall to the side ditches to carry away the surface drainage promptly.

3. Where possible keep the grade slightly above the adjoining land to provide better sub-drainage.

4. Establish the grade line in such a manner, consistent with the above, that the fills or embankments may be made from nearby excavations or cuts, balance the cuts and fills in other words.

5. Modify heavy grades around curves and avoid steep grades near bridges, turns, railway crossings, or intersections.

6. Connect the tangents of two intersecting grades with a vertical curve.

7. Break up long continuous rises with level resting places at convenient intervals.

Although it is not often possible in towns or cities to follow all the principles outlined for fixing the location and grades of country roads, they should be made to govern where practical. Improvements already in, and the effect of grading on tbe abutting property should, however, be given due consideration. On the main thoroughfares every attempt should be made to secure satisfactory grades, while on the side streets the percentage of grade may be of secondary importance. A great deal of trouble can be saved the City and a great deal of expense to the property owners, by fixing the grade on all existing streets whether it is intended to actually grade them soon or not, so that any sidewalks laid or buildings erected conform to the street as it will some day be improved. The established grades should be a matter of record in the city clerk's office so that any competent surveyor can furnish the property owner with the proposed elevation of the street in front of his property. No new streets should be accepted by the city unless the location and grades are satisfactory and to the benefit of the city. These represent the fundamental principles of city planning which is essentially a proper guiding of the city's growth.

In establishing grades on streets, attention should be given to surface drainage. Undue concentration of storm water at any one point should be avoided as well as intersections or places in the street which hold water. Street intersections should be as nearly level as possible and the position of future catch basins and lines of sewers should be carefully looked into. Well planned streets are a source of beauty and satisfaction to a city that the residents cannot afford to be without. Once improved it is scarcely probable that the location or grade of a street or road will ever be materially changed. They become permanent assets and should be given all the study and careful consideration possible. The advantages to be gained by improved roads and streets should be kept in mind, so they can be made to return the largest dividend in satisfaction and service.

CHAPTER III

THE SUB-GRADE AND FOUNDATION

AFTER THE PRELIMINARY ENGINEERING work of locating the line and fixing the grade of the highway has been completed, the actual improvement work may be commenced. From one-half to three-quarters of the cost of this improvement may be considered as absolutely permanent and should be treated with all the care due a permanent investment. If designed with a view to future needs and in accordance with sound engineering principles, the grading, the structural work and the preparation of the sub-grade including surface and sub-drainage should never need replacement, while the foundation and the wearing surface may be considered more or less permanent depending on the kind of construction employed and the care it receives in use. In many discussions on street and road improvement, the property owners consider the surfacing material only, without realizing that the wearing surface is but a relatively small portion of the total cost and that no pavement will give entire satisfaction unless the sub-structures are carefully designed and constructed.

The first things to be planned and built are the structures necessary to provide for surface drainage and the crossing of streams or other obstructions. To avoid legal claims for damages the surface drainage should always be carried in the natural channels unless the consent of the owners of property is obtained for its diversion. Culverts should be of ample capacity to take the water from the heaviest storms. Records of the height and amount of water in the natural drainage channels during the worst storms give the best means for determining the size of culverts or the waterway for bridges. If these are not available or are unreliable, one of the many empirical formulae may be used when accompanied by good judgment. About the best of these is the Burkle-Ziegler, formula, $Q = RC \sqrt[4]{\frac{S}{A}}$ where Q is the cubic feet per second per acre reaching the culvert; R is the average rainfall rate during the heaviest storm in cubic feet per second per acre; C is a constant varying from 0.75 for paved streets in cities, or 0.62 for ordinary city streets to as low as 0.25 for farming country; S is the general fall of the drainage area per 1,000 feet; and A is total drainage area in acres. In the absence of definite records the average run-off during heavy storms is taken at one inch per hour. One inch rain over one acre gives 3,630 cubic feet so that this rate is almost exactly equivalent to one cubic foot per second per acre, and R is 1. The size of the culvert to care for this computed discharge depends on the material used, the shape and the grade to which it is laid. Another formula which has been used is the one proposed by A. N. Talbot. The cross sectional waterway area of culvert in square feet

$$= C \sqrt[4]{(\text{Drainage area in Acres})^3}$$

C in this formula is a variable coefficient which for steep and rocky ground may be taken at 2/3 to 1; for rolling farming country subject to

floods at times of melting snow and with the length of valley three or four times its width, C is about 1/3, and for longer valleys and flatter country without snow danger, C may be 1/5 or even less. (See Fig 10.) By checking existing culverts which have proved

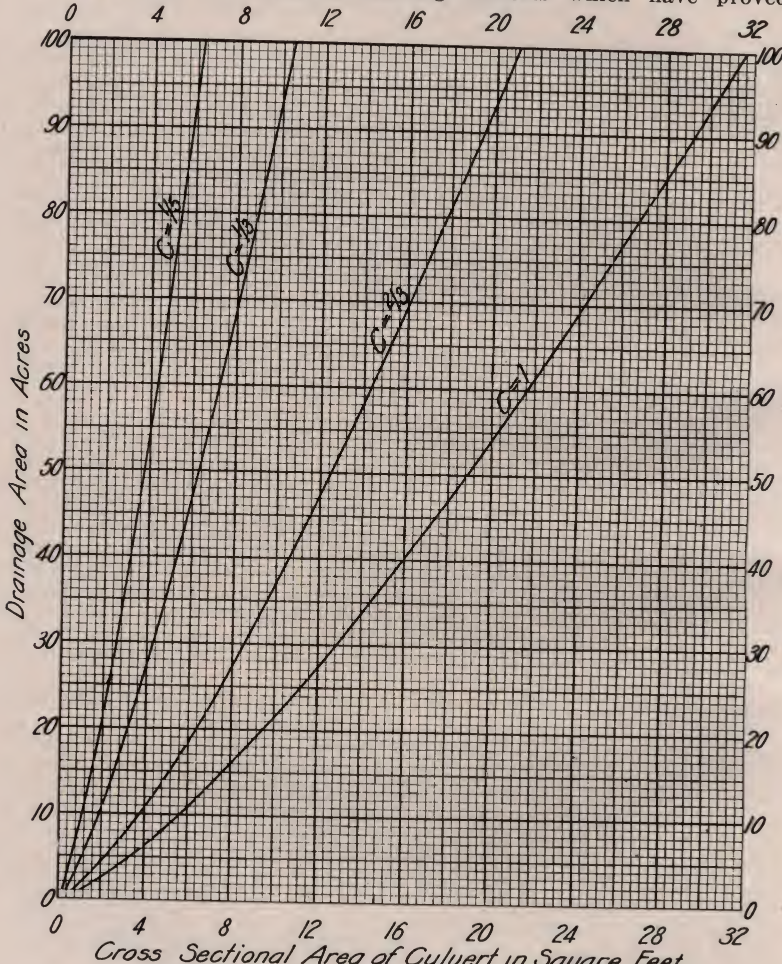


Fig. 10—Culvert Areas by Talbot's Formula.

satisfactory with this formula, values for C may be determined for use in designing new culverts under like conditions. The formula is not difficult of operation even without the use of logarithms when it is remembered that the fourth root is obtained by taking the square root of the square root.

The inlet to the culvert should be so placed as to receive the water in a direct line with the channel and it must be protected by a headwall to prevent the water washing the surrounding dirt away. The inlet should also be placed high enough so that it will not fill up with mud and the waterway approaching it should not be too steep, so as to prevent the opening from being clogged with brush, leaves and dirt. The culvert itself must be as straight and short as possible, and discharge the water in the line of the natural channel. No storm water drain should be less than 12 inches in diameter and 18 inches as a minimum would be better for roads, where pipes are cleaned at infrequent intervals. On account of cheapness and permanence of construction, drains up to 30 inches in diameter are usually heavy vitrified clay or concrete pipe laid with tightly packed cement mortar joints and with small concrete or brick headwalls. Where a larger size is necessary and two or three lines of pipe are not advisable it has been customary lately to build some form of box or arch reinforced concrete. While this is satisfactory it may frequently be found cheaper to construct culverts up to 20 foot spans as brick arches sprung from brick or rubble masonry side walls, thus utilizing materials at hand and eliminating expensive form work and the procuring and cutting of various sizes of reinforcing metal.

Brick masonry is permanent and there is little chance of failure; it can be placed by small gangs of workmen in a short time and with a minimum of equipment and material. The portions of the kilns of paving brick not suitable for paving purposes can be used at low cost to advantage in this work, and the chipped or broken paving brick make ideal floors for culverts. The table shown gives the proper thickness of the brick arching and size of abutments for different spans. Where rough rubble masonry is used for the side-walls the thickness shown should be increased 10 to 20%. All work and materials are assumed to be first class and all joints filled with one to three Portland cement mortar. Where paving brick with lugs are used, the lugs should be turned so as not to receive the bearing.

TABLE OF PRINCIPLE DIMENSIONS OF SEGMENTAL BRICK ARCH CULVERTS.

Span in Feet	Thickness of Arch Ring in Inches	Maximum Height of Abutment in Feet for Minimum Thickness	Minimum Thickness of Abutment for Arches of 120 Deg. in Feet	Cross Sectional Waterway Area in Sq. Feet
3 ft.	8 in.	2.5	2.0	9.3
4	8	3.0	2.3	15.3
6	12	3.8	3.0	30.2
8	12	4.6	3.7	49.9
10	16	4.8	4.2	68.5
12	16	5.2	4.5	91.9
14	20	5.7	4.7	120.0
16	20	6.0	4.9	148.5
18	24	6.3	6.1	179.8
20	24	6.6	6.3	214.0

Fig. 11—Reinforced Concrete Arch Bridge Faced With Brick and Stone.

All culverts unless specially designed for concentrated loads should have at least one foot of earth covering on top of them. When the headroom available is insufficient to permit of the larger sizes of arch culverts, two or more small sized lines may be built or a reinforced concrete girder bridge may prove economical for spans from 15 to 50 feet. In all cases care must be taken to provide adequate foundations extending below the frost line, abutments capable of withstanding the arch thrust, and well tamped earth on each side before filling on top of the arch. Ample provision should be made against washout of either the culvert itself or the road by suitable parapet and wing or headwalls. Spans of over 35 feet and over streams or other obstructions are classed as bridges and require special treatment. For permanence and low cost of maintenance, reinforced concrete has won a well deserved reputation for this class of work. Where it is desired on account of its location to emphasize the aesthetic qualities of a bridge, its beauty has frequently been much enhanced by the use of brick paneling, coping or facing. The brick facing for the exposed surfaces may often be laid up inside the wooden forms, provision being made for proper bond to the reinforced concrete which is placed afterwards.

The actual work of grading the street or road is usually carried on immediately following the surface drainage structural work. In addition to seeing that the grading is carried to the full width and to the proper level, attention must be paid to a number of other points. The sides of deep cuts should be given enough slope so that they will not wash down into the ditches. Rock excavation should be carried low enough to provide for at least six inches of backfilled earth between the rock and the pavement foundation, and the surface of the rock should be left so that it will not hold large pockets of water. Fills of more than four feet in depth should be made in not over four foot layers and each layer should be carried out the full width of the fill to the side slopes. Dumping of earth for a fill over the end or sides will not thoroughly compact the embankment and the fill may continue to settle for several years. The fills should be brought up on the sides at a slope which will insure stability of material, in any case not less than one and one-half feet horizontal to one foot vertical rise. If rock is used in making fills, about equal quantities of earth should be mixed with it, but logs, brush or other perishable material should not be allowed to remain. Fills made on a side hill often require that the original ground surface be ploughed and stepped to prevent the slipping of the new material. Where fills of less than one foot are made the original surface should be ploughed so that the new material will knit with the old. It is to be expected that embankments of all heights will settle about 10% of their height the first year after construction, but of course this will vary with the care used in building them, the season of the year and the kind of soil. For this reason where there are many fills over five or six feet deep the grading should be completed if possible a year in advance of the paving. Some cities have gone to the expense of compacting heavy fills as they are made in thin layers with a steam roller so that the paving could follow immediately.

Ample side ditches should be provided for surface and subdrainage water, and these should discharge as frequently as

possible into the natural watercourses so as to avoid having the side ditches carry the storm water any great distance or in any great volume. Frequently the side gutters must take not only the storm water which falls on the road itself but also the water from the adjoining land, and this condition must be recognized in designing the side ditch. Where there is danger of the ditches being washed

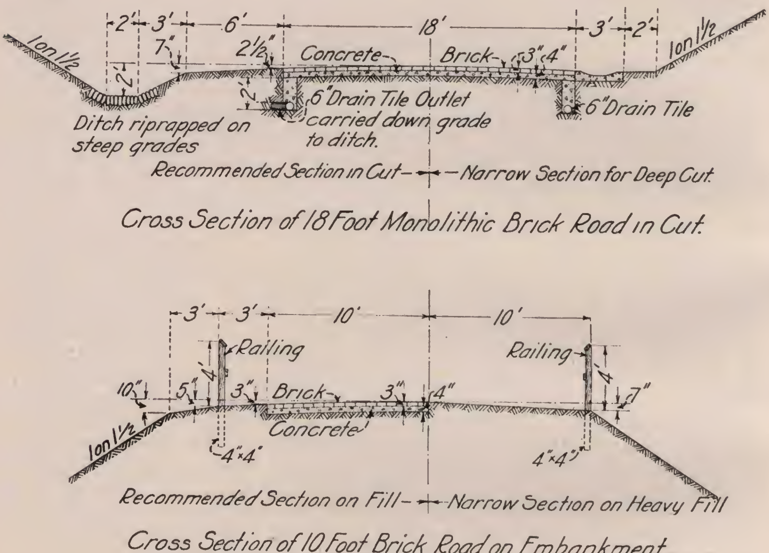


Fig. 12—Brick Road Cross Sections.

out on account of the steepness of the grade, low rock dams should be built across the ditch at frequent intervals, or the sides and bottom riprapped with heavy stone.

It always pays to be certain that the surface water will be quickly and safely removed from the road or street. When not properly handled, it frequently causes very serious and expensive damage.

In spite of all that has been written or said in regard to proper sub-drainage for pavements, this important feature is too often disregarded or ineffectively handled. This is probably because no hard and fast rules can be laid down to cover this part of the work, but each case must be treated individually and in accordance with the experience and best judgment of the Engineer. In the first place care must be taken to prevent any surface water reaching the sub-grade. The system of sub-drainage should be designed to

promptly remove all ground water for a depth of at least two feet below the surface of the pavement. This will prevent the sub-grade from becoming softened or heaved by frost. The load a given soil will support depends on the amount of moisture in it. Coarse sand and gravel are practically self-draining and when there is an impervious pavement to prevent surface water reaching the sub-grade the only precaution necessary is to see that ground water from the sides of the cuts and any springs are taken care of. The difficulty of sub-drainage varies with the character of the soil, fine sandy loam on account of its capillary action and stiff clay being the most difficult. The clay and gumbo soils, because of their low load supporting power even when dry, and because of the difficulty in removing the moisture from them, require the most careful attention.

The drainage of the sub-grade is usually accomplished by a system of lines of clay or cement tile laid in trenches three or four feet deep, although where rock is plentiful, stone spalls and boulders may be used as a "blind" drain instead of the tile. In towns or cities where there are no side ditches, the lines of tile are laid parallel to the curbing and connected to manholes or catch basins at frequent intervals. On country roads, paved not more than 20 feet wide, the drain tile are usually laid longitudinally under one or both sides of the pavement and having outlets in the side ditches or surface drainage culverts. The drain tile is usually four to eight inches in diameter and outlets are provided and the lines are spaced close enough together to care for the expected ground water with the size of pipe selected. Drains smaller than four inches should not be used as they have a tendency to silt up. They are laid in trenches of at least two feet in width butt jointed, carefully graded to the outlets and covered with stone spalls, small boulders, coarse gravel or other porous material. If possible the entire trench should be backfilled with coarse material, but in any case broken stone or other coarse material should be placed for a depth of at least one foot over the top of the tile and the full width of the trench. The outlets should be carefully protected from breakage and covered with wire netting to prevent the ingress of vermin. Drains should be laid at least 2 feet below sub-grade and 4 feet is often better. The depth of drains is an important factor in determining the area drained and also the uniformity of drainage.

Determining where sub-drain tile are necessary requires careful study and a thorough knowledge of soil conditions during all seasons of the year. Cuts, the upper side of side-hill roads, low ground, springs and boggy sections nearly always require some underdrainage. Since the expense of construction is light, it is best to be on the safe side and install drain tile in all cases of doubt.

It should be remembered that the sub-grade is what must finally carry all loads. The pavement foundation simply distributes the load over a sufficient area of sub-grade. By providing a sub-grade of uniform density and of proper grade and cross section, by excluding the surface water with an impervious pavement and by promptly removing the seepage and ground water, the bearing power of soils is increased from three to ten times with a corresponding saving in the amount and cost of the pavement foundation.

After excavating the sub-grade to a uniform grade and crown it should be rolled with a heavy roller. The rolling will compact

the upper soil layer and iron out small unevenesses, but must not be depended upon to sufficiently compact trenches or deep fills. Its chief function should be to discover soft spots and variations in the bearing power. of the sub-grade. These places must be dug out and backfilled with other material or stiffened by the addition of broken stone, cinders or sand, so that the roller will finally indicate a uniformly compacted, firm, unyielding sub-grade. Before the final passage of the roller, it is well to drag the sub-grade with a templet in order to level up the depressions and bumps. This will save in the amount of foundation and insure a uniform thickness. A sub-grade prepared with the care indicated above will support from one-half to eight tons per square foot depending on the nature of the soil. On the uniformity of the bearing power which can be developed from the sub-grade depends in a great measure the quality and thickness of the pavement foundation.

The purposes of a foundation may be itemized as follows: (1) to distribute the wheel loads over a sufficient area of the sub-grade so that the bearing power of the soil will not be exceeded; (2) to bridge over soft spots in the sub-grade; (3) to provide a rigid, uniform bed for the laying of the wearing surface, and (4) to protect the wearing surface both by the absorbtion of shocks due to the impact of swiftly moving loads and by maintaining the surface to uniform grade and crown without undue deflection under the heaviest loads. To accomplish these purposes, sand, gravel, crushed rock, brick, concrete and other materials have been used. On account of its cheapness, ease of construction and great strength, Portland Cement concrete is much the best under modern traffic conditions. Where some of the functions of the foundation, however, can be combined with the wearing surface as in monolithic brick pavement, old macadam, gravel or crushed rock may be used. It is much more difficult and frequently as expensive, however, to properly prepare such a base as to lay a concrete foundation of equal or greater strength.

The thickness of the concrete base necessary to answer the purposes for which a paving foundation is intended, is therefore, entirely a matter of engineering design and depends on the character of the sub-grade and the care used in its preparation, on the weight and kind of traffic, on the surfacing material used, and on the strength and quality of the concrete itself as determined by the quality of the aggregate, the amount of cement used and the care in its construction. It is as meaningless to say that all pavements should have a six inch concrete foundation as that all shoes shall be No. 8 size. The base must be designed to fit the individual case.

There are many cases where a six inch foundation is inadequate and other cases where it is stronger than necessary. Unfortunately errors in foundation design and construction have been numerous and fully one-half of the defects in pavement can be traced to carelessly or improperly built foundations. There is no reason, however, why a four or five inch foundation under favorable soil conditions should not be ample for moderate traffic on country roads, provided extreme care is taken in the preparation of the sub-grade and in the mixing and placing of the concrete. On the other hand streets under continuous, heavy, swiftly moving traffic in a large city where the pavement is being constantly opened for sewer and

water connections and where sub-grade conditions are unfavorable, may require a mass and strength of foundation, obtained only by a thickness of concrete of eight to ten inches. Intead of adopting a universal thickness for the concrete base on any one highway, it might be economy in some cases to vary the depth, using a heavier base on the portions of the road where the sub-grade was more uncertain and difficult to drain. As a general rule, however, it is better to have a thicker base of a lean mixture than a thin base of a rich mixture. The strength of the base acting as a beam varies as the square of the depth, so that concrete of the same proportions is over twice as strong in a six inch base as in a 4 inch base, and four times as strong as in a 3 inch base. In other words the proportions of the concrete might be adjusted so as to give a unit strength in the 6 inch base of only one-fourth the unit strength of the 3 inch base and yet both would be equally capable of carrying loads over soft spots in the sub-grade. The thicker base would moreover have twice the weight or mass for absorbing the shocks and vibrations due to rapidly moving traffic, an important item not usually considered in highway design. The saving in cement and labor would probably not entirely offset the additional cost of sand and rock, but where the latter may be had at average prices, a 1-4-8 concrete 6 inches thick can be placed at about 50% increase in cost over a 1-2-3 concrete 3 inches thick, and the thicker base will be one-third stronger acting as a beam. A slight defect or any lack of uniformity in the concrete is much more serious in a thin base and consequently greater care must be used in mixing and placing the concrete and in preparing the sub-grade.

The wearing surface selected and the method of laying it, also influences the depth of foundation required. It is evident that a cement grouted brick which distributes the concentrated wheel loads over a considerable area of the top surface of the base will require less strength in the base, than a thinner wearing surface which has no distributive effect. A pavement which presents a smooth uniform surface will also reduce the impact shocks of swiftly moving traffic and require less foundation than one which is forever out of repair, uneven, loosened or full of depressions.

The advent of the motor truck with its extremely heavy loads carried at comparatively high speed has complicated the foundation problems of the highway engineer. Where formerly the heavily laden farm wagon, giving a load on the surface of the pavement of about 350 pounds per inch width of tire and moving at 3 to 5 miles per hour, was about as heavy as the pavement was required to care for, now truck loads of 5 to 10 tons moving at 15 to 25 miles an hour and giving loads of from 500 to 1,200 pounds per inch width of tire are not uncommon. The engineer must bear these changed conditions in mind in designing his pavements. Even the best constructed pavement cannot, however, withstand the continuous abuse some of them are being subjected to, and it will be necessary in order to preserve the investment of the taxpayer for the use of the many, to prevent by strict regulation the improper use of our pavements by the few. Every community should have a law regarding width of tires on vehicles, prohibiting a greater load than 700 or 800 pounds per inch width of tire, which will correspond to a 9 ton load distributed on four wheels with 6 inch width of tires. The speed for the maximum

load should be limited say to 12 miles per hour and the maximum speed for the lightest loads should not be more than can be considered safe to other traffic. License fees should also be graded in accordance with the capacity of the vehicle and the weight per inch width of tire making the rate so high for the excessive loads that it will discourage their use. All proper means should be made to regulate the traffic and enforce a reasonable law regarding loads. The Engineer can then have some basis for economical design and our streets and roads will not be damaged by the few users who do not have properly designed vehicles. Tractors with iron lugs on the wheels should not be allowed to use any pavement unless the wheels are first banded or planks are laid for them to travel on.

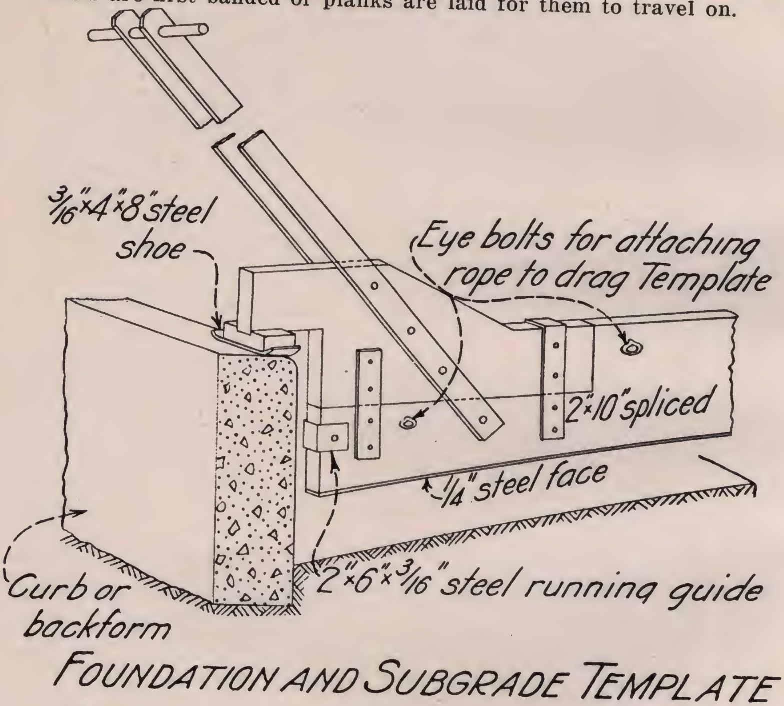


Fig. 13—An Essential Tool for Good Pavement Construction.

In the actual construction of the concrete foundation on the rolled sub-grade there are a great many things to watch. The cement must be of good quality and sound, the sand clean and coarse, and the crushed stone or gravel clean, properly sized and sound. These must be combined with clean water into a homogeneous mixture of the right consistency and proportions, and spread on the sub-grade to a uniform thickness with the top smoothed and leveled true to grade and crown. The usual proportions for the foundation are one part cement, three parts sand and five or six parts broken stone or gravel,

although there should be no hesitancy on the part of the engineer to vary from these proportions if strong enough concrete can be obtained at lower cost, or if reduced thickness requires a richer mixture and more strength. Bank run gravel should never be used without screening and recombining the sand and coarse gravel in proper proportions. The crushed stone and gravel should be screened of all sizes that will pass a quarter inch screen and the size of the largest fragment should not be more than one-half the thickness of the concrete base. The more uniformly the sizes are graded between these limits, the denser and stronger the concrete and the easier it can be worked and laid. There is a tendency among the contractors to hurry the time of mixing the ingredients by adding an excess of water. No mixer should be allowed into which the concrete ingredients including the water cannot be accurately measured and a minimum time limit should be fixed for mixing each batch. A little experimenting in longer mixing and the use of less water will produce surprising results in the quality of the concrete. To avoid shoveling and mixing with dirt, the concrete should be deposited from the mixer close to its final position in the foundation, leveled off and tamped to a dense, uniform, quaking mass. Where there are no curbs or where the curbing is constructed at the same time as the foundation it is necessary to have side forms set in advance of the concrete. With a little care in setting, these forms can be used as a guide for the templets to level the sub-grade and the top of the concrete foundation. The use of a templet, the ends of

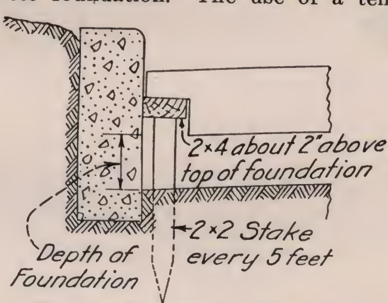


Fig. 14—Support for Templet in Center of Wide Street or Where Curbs are Uneven.

which rest on side forms set to line and grade or on the curbs, for finishing the surface of concrete foundations is strongly recommended. (See Fig. 13). In no other practical way can a more uniform thickness or surface finish to the concrete base be secured. Even where the coarse aggregate in the concrete is too large or angular to permit dragging the concrete with the templet, it can be used as a guide to the leveling, as a tamp and to test the trueness of the surface. The templet should be substantially constructed of wood or steel and cut or bent to accurately fit the proposed upper surface of the foundation when resting on the curbing or side forms. On wide streets it may be necessary to place a longitudinal guide strip along the center line and use two templets, the center form being removed as fast as the concrete is placed. (See Fig. 14.) The templet saves the contractor a great deal of time and waste material and makes it easier

to lay the wearing surface while it insures the engineer a uniform thickness of foundation and a true and even surface for his pavement, two essentials of durability. In the laying of monolithic brick pavements, which will be described in a later chapter, a templeted, uniform foundation surface is absolutely necessary.

After the concrete has been placed, care must be exercised to see that it is not disturbed while gaining strength and that it receives sufficient moisture to develop its full strength. In dry, warm, weather the sub-grade should be well soaked with water in advance of the laying of the concrete, and the finished concrete should be protected from drying out by covering with water, moist earth or by frequent sprinkling. These precautions can be easily taken and are essential to proper curing. It should be borne in mind that cement gains strength very slowly at low temperatures; scarcely at all below 40 degrees F. For that reason the length of the period of curing will depend on the weather conditions. Under the most favorable conditions at least ten days should elapse between the time of the placing of concrete and the permitting of traffic on the finished pavement, and much would be gained by lengthening this period. Time should be given for the concrete to attain a large share of its maximum strength. The laying of the brick wearing surface can proceed, of course in the interval and after the base has attained strength enough to sustain the roller.

To summarize this chapter, therefore, emphasis should be laid on the following important points:

Streets and roads should be graded in a permanent manner and precautions taken against undue settlement of fills or slipping of the sides of cuts. The surface drainage should be taken care of by ample side ditches, catch-basins, sewers and culverts, all built in a permanent manner and with a view to the prompt removal of all storm water without damage to the highway or the abutting property.

Since the sub-grade ultimately carries all loads on the pavement and since its sustaining power varies inversely with its saturation, great care should be taken in its preparation. By means of permanent, well designed systems of sub-drainage, all ground water should be removed, and by care in rolling, the entire sub-grade must be brought to a uniform surface of equal bearing power throughout.

While other forms of foundation may be used successfully under proper soil conditions, the cement concrete base is usually the best and most economical. By varying the thickness and the proportions of the ingredients, a foundation can be designed capable of taking care of all conditions of soil and traffic, and suitable for fully developing the wearing qualities of the pavement surfacing.

Care must be exercised in the selection of the ingredients of the concrete and in its mixing, placing and curing, so that the money invested will return the largest dividends in a dense, homogeneous concrete of uniform thickness and with the strength developed to the fullest extent.

The design and supervision of the construction of pavement foundations call for the best judgment and thought of the trained engineer. By giving the strictest attention to every detail, foundations may frequently be constructed at less cost than the present standard and at the same time avoid many of the defects which now occur.

CHAPTER IV

MANUFACTURE OF PAVING BRICK

ALTHOUGH THE HIGHWAY engineer cannot be expected to master all the mass of technical detail involved in the manufacture of paving brick, a thorough understanding of the fundamental principles and general processes is practically necessary if he expects to construct the best brick pavements. A knowledge of the working of a brick plant will enable the engineer to judge the material to better advantage, and to lay it with greater assurance of securing a satisfactory pavement.

The manufacture of brick is one of the oldest industries known. The making of paving brick is a more recent outgrowth of the parent industry, which was fostered by the brick men who saw in the durability of the early brick pavements an increasing demand for brick made especially for paving purposes. Paving brick manufacture has since attained considerable importance in the clay products line and has become a highly specialized branch of the brick industry calling for the best technical advice and expert management. It used to be thought that anyone could start a brick plant near any convenient bed of shale or clay, and with temporary equipment and cheap labor, turn out a brick suitable for either buildings or pavements. Engineers began, however, to discriminate in the quality of the brick they used for paving, and the manufacturer was obliged to call in the mechanical engineer and ceramic expert to devise machinery and means for increasing the quality and uniformity of his product.

Since the manufacture of brick is not based on any secret or patented process and the raw materials are found in nearly all sections of the country, the use and sale of the finished product depend entirely on furnishing the best material at the lowest price. This has necessitated a more permanent plant construction, the installation of additional machinery and many labor and fuel saving devices, and the employment of higher priced labor and management.

In this keen competition for business, the quality and uniformity of paving brick have been brought to a high state of perfection without a corresponding increase in price. A study of the various operations in a modern brick plant to which the raw material is subjected before it is ready to lay in the street is not only interesting but instructive.

Clays are formed, geologically, in former river, lake or sea beds by deposits of a silicate of alumina usually mixed with other substances. Brick clays are generally obtained from former sea beds and are the most extensive and the most uniform both in depth and quality.

Shale from which the majority of paving brick are manufactured, is clay which has been consolidated by great natural pressure. Brick clays or shales must possess a certain amount of plasticity in order to be workable. Plasticity of clay is a characteristic which distinguishes it from nearly all other mineral substances and may be defined as the property of a body which enables it to absorb water in such a

manner that the properly moistened body yields to mechanical pressure, but when the pressure is removed, the shape of the body remains as though the pressure were still acting on it. Some clays are deficient in plasticity and are called "lean," others are over-plastic and are called "fat." By proper mixing of clays or other material it is often possible to obtain a suitable product from clay beds which would otherwise not be workable.

The plasticity of shales must, of course, be developed by grinding. The other properties of a clay or shale which make it suitable for any particular class of brick are due in large measure to the impurities contained, such as ferric oxide, lime, silica, magnesia, potash and soda. Some of these act as fluxing agents and determine the temparaure at which the clay vitrifies; others prevent warping, shrinking and cracking, and still others add toughness and hardness to the brick. The iron oxide, for example, besides acting as a fluxing agent for the silica, is responsible for the red color and increases the toughness. The shade or color is determined more by the form in which the iron occurs than the amount and also by the method of burning, by the fuel used and by other factors.

While certain fundamental properties must be possessed by a clay or shale suitable for the manufacture of paving brick, as will be seen later, the physical characteristics may vary considerably among different beds and in different parts of the country. Each bed of shale has its own peculiarities, which must be recognized in handling it to the best advantage. Consequently the details of the methods of manufacture at different brick plants will vary. What is said therefore regarding the process of manufacture covers the general practice of the average case, and cannot take account of the many variations necessary in the details.

The clay or shale is usually taken from a pit or quarry by blasting, steam shovel or mining methods. Care must be exercised in balancing the natural variations of the bed so that the mixture delivered to the mill is a uniform product. The shale is then crushed if necessary and delivered to the dry-pan, a circular pan with perforated bottom revolving beneath two heavy rolls. As a general rule the shale should be rather finely ground and screened over a screen or riddle having the proper sized openings as determined by the physical characteristics of the shale. Excessive fineness may cause checking or cracking in drying and aggravate laminations, while excessive coarseness will not develop the necessary plasticity. The screen in different plants, therefore, vary in size from 4 to 12 meshes per lineal inch. The material then goes to the pug mill or mixer, a long trough-like machine with a revolving shaft carrying a number of blades through the center, where the ground material is tempered and thoroughly mixed with water. In general the more the ground material is worked especially after the water has been added the more plastic, uniform and reliable the brick. The amount of water added must be very carefully watched as it is desirable to get a uniform product which can be properly worked.

The tempered clay is then dropped into the augur machine, which is essentially a closed mixer or pug mill operating under pressure. A heavy shaft with a screw thread or worm turns in a heavy closed cylinder, open, however, on top at the rear end to receive the

Fig. 15—The Shale Pit.

clay and on its axis at the other end to receive the mouthpiece or die as an outlet.

The action of the worm or augur gradually moves and compacts the tempered clay in the forward end of the cylinder where a gradual reduction in cross section of the cylinder further increases the compression in the clay. This compacted column of clay as it is pushed forward by the steady action of the worm is changed from circular to rectangular form by the mouthpiece, finally exuding from the die as a continuous column of clay of a cross section similar to the brick being manufactured.

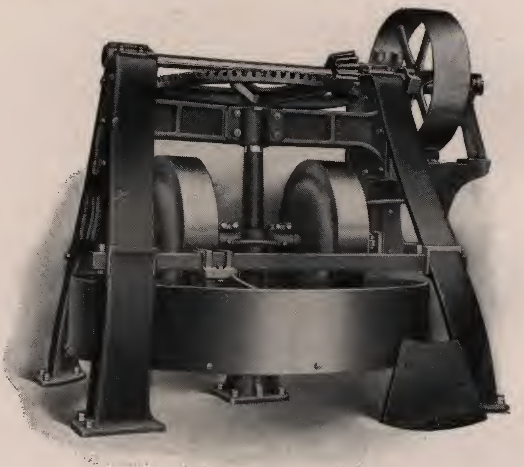


Fig. 16—The Dry Pan.

Since the clay column must have the greatest possible density, it follows that the augur must be built very heavy and strong in order to withstand the extreme pressures caused by compacting the stiff clay. In this machine the loose granular, moist particles of clay are transformed into a dense, compact, plastic column of uniform rectangular cross section. This transformation takes place in the forward part of the cylinder, especially in the tapering mouthpiece and the die. The design of the shape and length of this mouthpiece represents one of the most delicate engineering problems in connection with brick making. The shape and length of the taper depends on the clay, some clay taking a reduction in cross section more rapidly without detriment than others, and on the relative size of the cross section of the augur barrel and the die. The mouthpiece taper can best be determined by experiment but must insure a clay column of absolute uniformity and density throughout. The reduction in cross section must be gradual but too long a taper may give a brick with weak corners.

Let us consider for a moment what takes place in the forward part of the moulding machine. The worm compresses the clay in the front part of the cylinder in the form of a series of spiral layers. If

the clay has not been properly tempered, these layers are distinctly laminated, but even where there may appear to be perfect adhesion between the layers, it is probable that there is some slight line of demarcation due to the troweling action of the augur. As the cylinder

Fig. 17—The Augur Machine.

of compacted clay enters the tapering former, these layers are perpendicular to the axis of the cylinder. In being pushed through this mouthpiece, it is evident and has been demonstrated by experiment, that the central portion of the cylinder travels forward faster than the outer portion both on account of the reduction in section and the friction on the sides. The original verticle layers of the clay cylinder

therefore become long superimposed cones with their axis lying along the horizontal longitudinal axis of the clay column as it emerges from the die. The shape and length of these cones depend on the rapidity with which the clay has been reduced in section and on the plasticity of the clay. By changes in the tapering former they can be made to take any shape desired. It is probable also that the particles of shale themselves become arranged with their longer dimension parallel to the longitudinal axis of the clay column in passing through the tapering mouthpiece on account of the gradually increasing pressure, the internal friction set up by the reduction in section and the graduated variation in speed of travel. It will be shown later that while the burning greatly improves the clay structure, it does not make any radical change in the structure itself.

Fig. 18—The Parts to a Die.

Vertical Fiber Paving Brick are so named, because they are formed so that the axes of the cones and the elongated clay particles are vertical as the brick is laid in the street. In this position the brick are in the most favorable condition to resist wear and advantage is taken of the internal structure of the brick. It is scarcely correct to say that a vitrified brick is fibrous, but the term Vertical Fiber probably describes the condition better than any other. The advantage gained by so laying the brick that the internal structural layers are vertical is slight compared to the importance of the other steps in the process of manufacture, but it represents an additional factor of safety in the pavement and illustrates one of the many technical details the modern paving brick manufacturer is constantly adding.

The die through which the clay is forced by the augur machine, is a part of the former and is rectangular in section, the longest

dimension usually corresponding to the length of the paving blocks with an allowance for shrinkage in burning. The lining of the die must be smooth, true to shape and easily renewable as the wear is very great. It is lubricated with water, steam, oil or even electricity

Fig. 19—An Automatic Cutting Table.

and so designed that all parts of the clay column in passing through it, travel at approximately the same rate of speed; otherwise the central section is apt to travel faster than the edges and much faster than the corners, producing ragged edges and torn corners. The augur

machine and die must produce a homogeneous column of clay, thoroughly compressed and free from internal strains so as to prevent subsequent twisting, laminations and cracking during drying. The continuous clay column as it leaves the die is pushed by the force behind it over a moveable belt to the cutting table.

The cutting table is practically at the same level as the bottom of the die and must be constructed as carefully and substantially as a machine lathe. In one form of machine the floor of the table is slotted to allow the passage of the piano wires, which cut the clay column into blocks of the proper thickness. In another make of machine the column is pushed through stationery vertical wires. The wires should be as thin as possible and must be kept taut and clean so as not to tear the edges of the cut blocks. The repress was invented and used formerly to correct the defects in the clay structure due to faulty augur machines, dies and cutting tables.

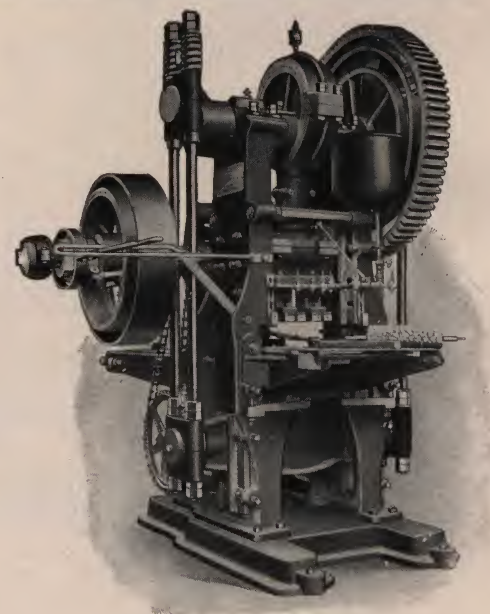


Fig. 20—The Repress.

The repress consists of a metal box with an open top of the size of the block cut from the clay column, set on a strong iron frame and with a plunger the size of the box opening which comes down on the clay block in the box with a steadily increasing pressure.

The box or repress mould is so shaped that round corners, lugs and the trade name of the brick are formed. We have seen that the clay column as it emerges from the die has a definite set or structure. After being cut into blocks, if these blocks could be repressed in a true mould with pressure exerted in the same manner as

in the augur machine, the additional compression would undoubtedly add to this set, but any change in the shape of the clay blocks or direction of the compressive force means a disruption of the original form. No repressing machine has been designed which exerts equal pressure on all sides of the clay blocks and the form is also changed by the addition of lugs and round corners. The press box must be slightly larger than the cut clay block it is made to receive so that the block can be dropped in easily, hence the repress compresses the block in one direction but expands it in the other two dimensions. Experiments and measurements invariably show that the repress increases the cubical volume of the clay block. The rounded corners are a necessity in the repressed brick as it would be impossible to maintain the square edges in the mould. They also add to the appearance of the paving brick and enable it to show a lower percentage of loss in the rattler. All tests of the material however, seem to show that a well made, non-repressed block is much stronger and freer from structural defects than when subjected to repressing. Since the development of brick machines and automatic wire cutters has made possible the forming of a high grade block, the wire cut product has been rapidly displacing the repressed block. There are two methods of forming the clay blocks by the wire cut process.

In one the wires of the cutter are guided in narrow waved and straight slots cut in steel plates placed above and below the clay column thus forming two knobs or lugs on both the upper and lower edges of the cut block. The alternate slots are straight so that the lugs are formed on only one side of each block. On account of the tilting of the wires in passing through the slot, the knobs are beveled, projecting the furthest on the upper and lower surfaces of the block. This form of block is known as the Dunn Wire-Cut-Lug Paving Block, and this form of wire cutting machine is patented and can be used only by manufacturers licensed by the patentee. The lugs are accurately formed and provide uniform spacing of the blocks in the street while the slightly roughened wire cut surface forms an excellent bond with cement grout when it is used as a filler for the joints of the pavement. The wearing surface of the brick is, however, the smooth surface formed by the die, and the conical clay layers are horizontal intead of vertical as laid in the pavement. Two of the four edges of the brick exposed to wear in the street are also necessarily slightly rounded as they are formed on the clay column by the die. The depth of the brick as a pavement wearing surface can only be varied in the wire-cut-lug brick by a change in the die or mouthpiece of the forming machine and on account of the difficulty in getting a uniform clay structure where there is considerable difference in the two dimensions of the die, a thin brick of standard length, if desired, is not practical.

In the other form of wire cut paving brick, the lugs are formed as two continuous parallel ridges on the top surface of the clay column by corresponding grooves in the upper face of the die. The blocks are then cut along a plane surface by straight taut wires. The spacing of the wires determines the depth of the brick and the die remains for all depth of brick the same. The brick as set in the pavement, are turned with a wire cut face uppermost, and the lugs projecting the same distance for the full depth of the block provide uniform spacing for the filler. This form of wire cut brick, the Vertical Fiber Brick

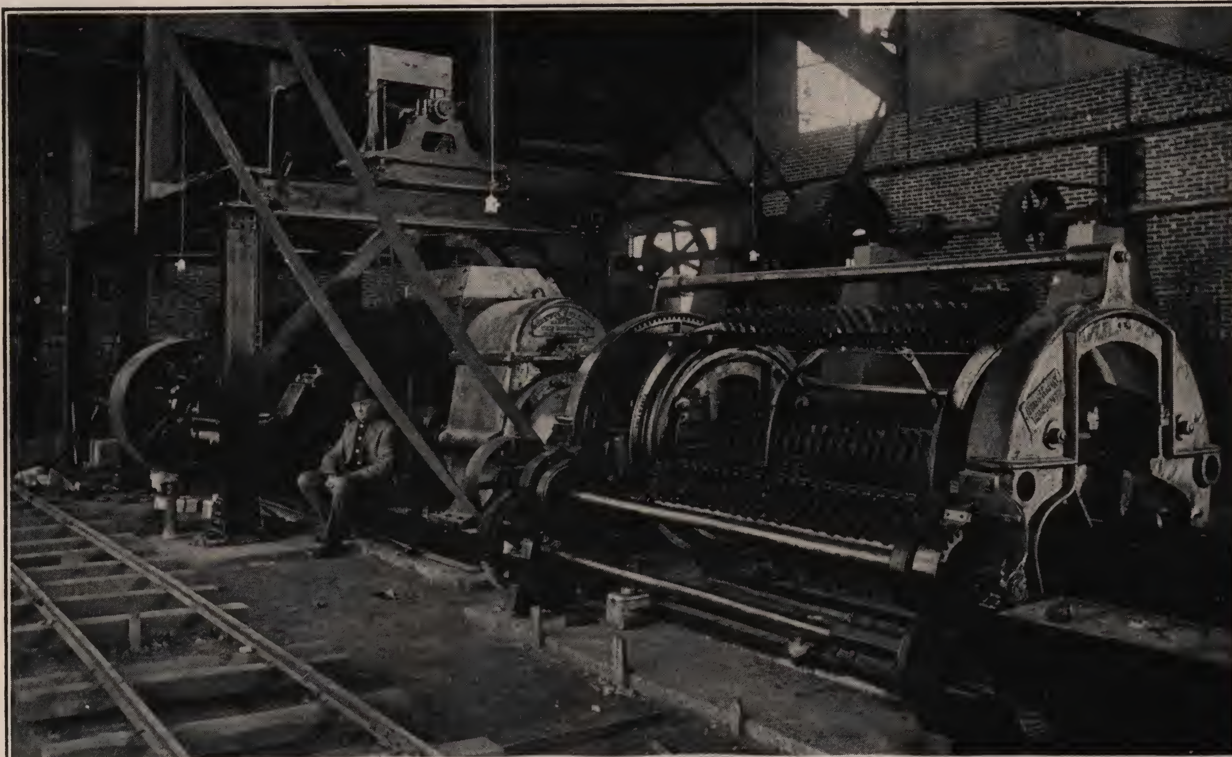


Fig. 21—Interior of Brick Plant Showing Pug Mill, Augur Machine and Cutting Table.

Block, has been shown to be so placed in the street as to take advantage of the internally formed structure of the clay. It is not a patented article but can be made by any manufacturer with the proper equipment. It can be made any depth desired. The reticulated wire cut surface is not slick, affording a good foothold and, when a bituminous filler is used, aids in retaining a carpet of bituminous material on the surface. All four edges of the brick surface are square making a uniform width of joint from top to bottom of the brick on all sides. The Vertical Fibre brick can also be so piled in the kiln that all kiln marks occur on the sides, leaving the bedding and wearing surface free from kiln marks or warps and thus providing a brick, which lays much smoother than other forms of paving brick. The area of the face of the Vertical Fiber Paving Block exposed to wear is usually 10 to 50% greater than other paving brick and there are consequently fewer brick to be laid to the square yard of pavement and fewer joints in the pavement. While a number of engineers continue to specify the old repressed brick block, the wire cut product is rapidly gaining in favor, the Dunn Brick in the Eastern and Central States and the Vertical Fiber in the Central Western and Southern States, the present tendency being to use a plain wire cut brick without lugs.

To continue with the process of manufacture, the clay blocks as they leave the repress or the cutting table as the case may be, are racked on small cars and wheeled to the drying room. Here a large portion of the moisture in the brick is removed by means of circulating steam, warm air or kiln gases. There are many different forms of driers depending on the nature of the clay but the rate of drying must be under careful control to prevent checking. The rate of drying can be partially controlled by the method of piling the brick, but the temperature in the drier must also be carefully regulated. There is seldom less than fifteen per cent of water in the clay block and the object of the drying is to remove as much of this at low temperatures as possible. The drying requires from one to three days and the brick as they come from the dryer are strong enough to be piled in the kiln.

Kilns are classed as single or intermittent, semi-continuous, and continuous, and each class is divided according to the path the heated gases from the fires take as up-draught, down-draught or horizontal draught. The majority of kilns used for burning paving blocks in the United States are of the down-draught intermittent type. Many plants have some form of continuous kiln, and this type has been growing in favor. Continuous kilns are especially suitable and economical for large plants which operate throughout the year and have a large output. When properly constructed and run, the percentage of No. 1 Pavers is equal to that obtained from the down-draught intermittent kiln and a considerable saving in fuel is made. The kilns must be very substantially constructed to resist the extreme heat and the expansion and contraction due to the variations in temperature. Adequate provision must be made to control the temperature in all parts of the kiln as this is the only way to secure a uniformly good product. The single down-draught kiln is rectangular or circular in shape with a number of bags or pockets on the inside along each of the side walls for the fires. The floor of the kiln is sometimes perforated throughout and always has numerous openings leading to flues which

Fig. 22—Exterior of Brick Plant (Being equipped to burn Producer Gas.)

run underneath the floor to the chimneys. Some kilns have but one chimney at one end connected by a central flue to the cross flues under the floor. Most brick kilns, however, have chimneys on the side walls between the fire pockets. The roof is a tight, flat, brick arch and at least one end has a temporary bricked-up doorway, which is torn out in loading and unloading the kiln. Baffle walls in front of the fire bags throw the heat along the sides of the kiln to the top where it passes down through the brick to the flues under the floor and thence to the chimneys.

The dried brick are piled in the kiln on edge 18 to 30 courses high, the spacing between the individual bricks being determined by their position in the kiln in order to retard or aid the passage of the hot gases. The arch doorway at the end of the kiln is then bricked up and the fires started.

There are three stages to the burning; (1) drying or water smoking stage, (2) the removal of vegetable and other combustible matter or oxidizing stage and (3) the vitrifying stage. The chief requisite of successful firing is a steady raising of the temperature to a sufficient height and at such a rate that the water and combustible materials may escape without damaging the goods, and expansion and contraction, which occur during heating, may take place sufficiently slowly to prevent the strength of the brick from being diminished. A well burned brick will not shrink further on reheating until the temperature is high enough to melt it, that is it has the greatest possible density. The first stage is one of the most delicate operations under the control of the burner as brick will be seriously weakened by the excessive pressures caused by large volumes of steam produced in the pores. The heat at this stage must be low enough to drive off both the free water and the water combined with the constituents of the clay without damage. The rapidity with which this can be done depends on the porosity and the inherent strength of the clay. The clay continues to shrink during the first stage.

After the smoke from the kiln and the temperature indicate that no more water is being driven off, the heat is gradually raised to between 600 to 1200 degrees F. and held at this temperature a sufficient time for all the combustible matter in the clay to be burned out and for the iron compounds to be fully oxidized. The brick swell some during the oxidization. If time enough is not given at this stage, a black core is apt to be formed. If the heating at this second stage is carried on with an insufficient supply of air in the kiln, the iron is reduced to a low oxide which combines with the silica in the clay and the gases given off from this slag cause the goods to be blown or cracked. The time required for the second stage depends on the nature of the clay and the size of the brick and takes from 10 to 60 hours. Swollen bricks are the result of carrying the heat to the vitrification point before the carboneous matter has been burned out.

The third or final stage of the burning carries the clay to a cherry red heat or 1200 to 2000 degrees F. The brick during this stage shrinks still further, loses its porosity and the particles melt together but not enough for the block to begin to flow or lose its shape. A much better product is obtained from a shale where there is a difference of several hundred degrees between the point where vitrification begins and where the block loses shape as there is less

danger of overheating and warping the blocks. It should be understood that the dictionary meaning of vitrification,—"to render glassy" —does not strictly apply to clay products. A glassy brick would be too smooth and fragile for paving purposes. As applied in a commercial sense to clay products, the term "vitrified" means that "a chemical action has taken place so that the clay particles have coalesced and become fused by the action of heat, forming a new homogeneous whole, but not that fusion has been made complete by bringing the entire mass to a semi-fluid state." As soon as the greatest number of brick possible in the kiln have been heated through to a temperature short of melting, the burning may be said to have been completed, the fires are drawn, all openings and dampers in the kiln closed and the brick annealed by slow cooling. The hot gases from cooling kilns are frequently used by special flues in the drier. Slow cooling of the brick is the secret of toughness. Drafts of cool air admitted through the fires during burning and through openings in the kiln during the first stages of cooling will chill the brick or cause air checking. There is always a tendency to hurry the annealing process, but the length of time allowed for cooling depends a great deal on the material, some clays only requiring 2 or 3 days while others take from 5 to 10 days.

In a properly burned kiln after it is opened, it is found that the top course is extremely hard, glassy and more or less air checked. Beneath this and down to within 2 to 10 courses from the bottom are the No. 1 pavers, sound, vitrified, strong, hard and tough. Beneath these are the hard burned "builders." The actual percentage of yield of good quality paving brick is subject to so many variables, that it is difficult to forecast. The temperatures in the kilns were formerly determined by the judgment of the burners and the amount of settlement as measured at intervals through openings in the top of the kiln. This was indefinite and unsatisfactory and although the amount of settlement still remains the key to proper firing it has been supplemented by using Seger Cones, specially prepared clay cones placed in the kiln which melt at a specific temperature, or by observations through peepholes in different parts of the kiln by means of a pyroscope, an instrument for measuring high temperatures by radiation. Some of the more modern plants have installed pyrometers in different parts of the kilns which electrically record temperatures throughout the burning and cooling process insuring accurate control at all times.

The engineer, however, is seldom able to inspect the entire process of manufacture of the brick he expects to use in a pavement and while a visit to a plant, which is well equipped with modern machinery and where up-to-date methods and careful supervision are in evidence, may greatly increase his confidence in the product, his problem is usually one of determining the suitableness of material as it is loaded in cars or delivered on the street. The qualities of good paving brick are the same as for any other paving material—hardness, toughness and ability to resist water and frost. Tests to determine these qualities have been evolved and standardized through years of experimenting. In the early days of brick pavement, tests for absorption, crushing strength, specific gravity, modulus of rupture and the like were required. The absorption and specific gravity tests were supposed to indicate the density and degree of vitrification, but the hardest burned brick which showed the lowest on these tests were frequently too brittle to stand traffic. It was found also

that equally good brick from different localities varied in specific gravity and amount of absorption within considerable limits so that any attempt to fix limits for these tests would either eliminate all but one or two manufacturers or pass No. 2 brick from plants which naturally gave low absorption and high specific-gravity tests.

Low absorption of paving brick is not essential to durability. Hard burned building brick, which absorb two to three times the amount of water a vitrified paving brick will take up, are unaffected by water or frost. About the same can be said of the tests for crushing and breaking strength; within considerable limits they depend on

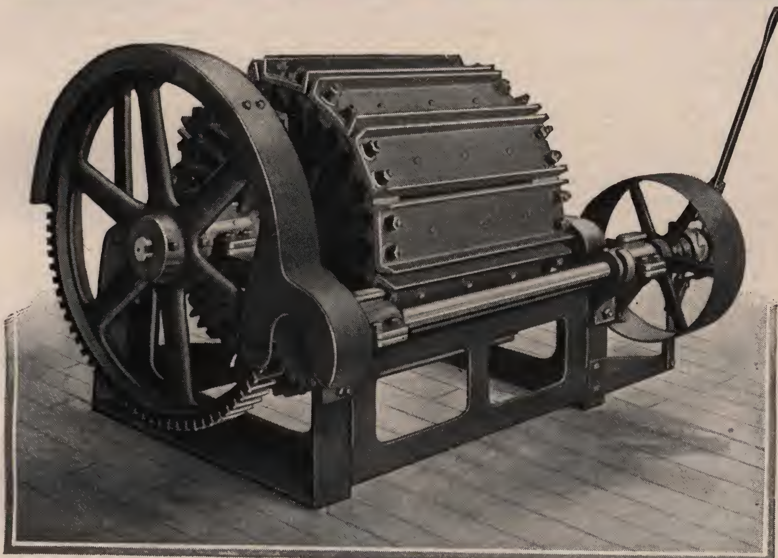


Fig. 23—The Standard Rattler.

the kind of clay used in the brick and are not indicative of a suitable wearing surface. In order to duplicate conditions of wear in the streets, the so-called "rattler test" was invented and adopted as standard in 1901 by the National Paving Brick Manufacturers Association. It was based on a long series of tests made on brick from old pavements and from plants throughout the country. The first machine, however, proved to be incapable of maintaining uniform conditions in successive tests and in 1911 the details of the construction of the rattler barrel were changed and round shot substituted for rectangular shot as the abrasive charge.* The rattler test consists briefly of measuring the wear on a sample of ten paving brick when tumbled loosely with 225 pounds of iron spheres 1⅞ inches in diameter and 75 pounds of iron spheres 3¾ inches in diameter in an iron chamber making 1,800 revolutions in approximately one

*See Page 106 for complete description of the rattler and method of making the test.

hour. The size and construction of the rattler barrel, the composition of the iron composing the abrasive charge, the speed of the rattler and all other details are carefully fixed or limited so that tests may be comparable. The standard test for instance requires that the speed shall not be less than 29.5 nor more than 30.5 revolutions per minute. A slight variation in speed beyond these limits may make a more severe test, while a greatly increased speed might be less severe. The brick selected for the test should always be dried if necessary as water in the brick not only affects the computation of loss but may also actually decrease or increase the amount of loss sustained. In other words, every effort should be made to carry out each test in exact conformity with the standardized requirements so that tests made on different shipments or by different manufacturers or for different streets, may be comparable.

The rattler test is intended to duplicate as nearly as possible the conditions met in a street pavement, the large spheres giving the sharp hard blows and the small spheres the grinding, polishing action received from street traffic. In this way the rattler tests not only the toughness and homogenity of the brick but also the hardness, strength and durability. It determines better than any other test the suitableness of brick for paving purposes.

The amount of wear on the sample of brick is determined by weighing them before the test and after the 1,800 revolutions in the rattler. The difference in weight is figured as a percentage of the original weight. The engineer usually fixes the maximum permissable percentage of loss and requires all brick furnished by the contractor to come within this limit.

In fixing a limited abrasion loss, the engineer must keep in mind the size and shape of brick he proposes to use, and the character of traffic the street or road to be paved, will receive. It is evident that the edges of the brick are the least able to withstand the punishment to which they are subjected in the rattler, and therefore a square edged brick like the Vertical Fiber or wire-cut brick will show a greater loss for the same quality of brick than a block the edges of which are rounded by the repress. Because of the greater ratio of edges to weight, a small sized brick will show a larger percentage of wear than a large sized brick. Allowance should always be made for these conditions or the engineer may find himself in the uncomfortable position of having specified a much higher grade of brick material for an outlying residence street where he uses two and one half inch depth Vertical Fiber than he must accept for a four inch depth block on a heavy traffic downtown street. The quality of the brick which will be acceptable should be decided after a study of the nature and probable amount of traffic which the pavement will receive in the same way that the depth of foundation and other features of the design of a pavement are determined. A failure to take account of all these conditions is nothing less than an economic blunder.

For the heaviest traffic streets in cities, a round cornered brick block, which shows an abrasion loss by the standard rattler test of 20 or 21 per cent or less will be entirely suitable. If a square cornered wire-cut-lug block four inches in depth is used, an additional allowance of two per cent should be made and the limits fixed at 22 to

23 per cent loss. For retail business streets, an allowable loss of 22 and 24 per cent for the repressed and square edged block respectively will prove economical. Where three inch Vertical Fiber brick are used on the business streets in towns or small cities a limit of 24 to 26 per cent gives an excellent quality of brick material, while on country roads or light traffic streets in towns a maximum limit of 25 or 26 per cent will serve. On account of its small size and the extra loss on account of an occassional broken brick in the rattler, a two and half inch depth Vertical Fiber brick requires an allowance of 26 to 28 per cent to insure the best grade of material, while a permissable loss of as much as 28 to 32 per cent is not out of the way for certain conditions of traffic and location.

The tendency of engineers has been to consider the brick showing the lowest per cent of loss in the rattler test as the best brick. It is undoubtedly the hardest and toughest material but it is the opinion of some engineers that extreme hardness and toughness are not neccessarily desirable for a pavement. Street traffic will cause practically no wear on a brick showing as low as 16 per cent in the rattler and the pavement will deteriorate only by the edges of the brick breaking off through failure of the joint filler, uneveness in laying or sunken places. It is conceivable that a softer brick, which would wear down somewhat under traffic, would produce a smoother appearance, and preserve an unimpaired surface longer than would a very hard brick.

Some slight abrasive wear is desirable on all kinds of pavements in order to keep them smooth and uniform. The harder the brick material, moreover, the greater the modulus of elasticity and therefore the greater the confined stresses in a cement grouted pavement slab caused by expansion and contraction.

It is apparent that the most desirable quality for a shipment of paving brick to possess is absolute uniformity. It has been shown that even under the most favorable conditions of manufacture, brick will vary slightly in quality due to variations in the clay, methods of handling, and degrees of heat in different parts of the kiln. Some engineers are fixing minimum as well as maximum limits to the rattler loss, while others have gone so far as to mark and weigh each brick before testing and requiring that the loss of any one brick shall not vary more than 3 points, for example, from the average loss of the whole charge. A severe requirement of this kind does not appear to be necessary. It is difficult to enforce, calls for greater refinement than the material or method of testing warrants, and would probably raise the price of the material out of proportion to any benefits received.

The specifications for a street subjected to very severe traffic conditions, might call for brick block not exceeding say 22 per cent abrasion loss and no single rattler test to vary more than 1½ or 2 points above or below a figure fixed by the manufacture as the average of the brick passing a 22 per cent test he proposes to furnish. This would insure great uniformity in the material, if the samples were selected and the tests made as prescribed in the standardized method of conducting rattler tests. (See pages 106 to 110.)

In all cases a much better selection can be obtained if the inspector for the engineer sorts and tests the brick at the manufacturing

plant. By this method any differences of opinion regarding the interpretation of the specifications can be adjusted before shipment begins, delays are avoided and the interests of both purchaser and manufacturer are protected. By testing the brick by courses in the kiln and loading directly into cars, a very uniformly burned product may be secured, and a competent brick inspector can make his selections to much better advantage at the plant than by sampling a carload after it arrives on the work. Plant inspection and acceptance is encouraged by the manufacturers and should be insisted upon by the engineers for all work of any magnitude.

Considerable space has been devoted to the rattler test, because it has taken the place of all other tests for determining the density, strength, hardness and toughness of paving brick. It has been shown in the description of the method of making brick that the defects likely to occur are of such a nature that they will be apparent on visual inspection or will show up by excessive wear in the rattler. Visual inspection will disclose the misshapen, warped, cracked, and off-size brick, that is, brick which will not lay evenly in the street, but must not be depended upon to pass on the quality of the brick material itself, especially if brick from different plants are to be selected. The rattler is best able to discover the soft, brittle or weak brick material. A specification, which limits the variation in width and depth of brick so that they may be bedded evenly and with uniform width of joint, rejects the badly chipped, broken kiln marked and warped brick which would make a rough and uneven surface, and throws out soft, brittle or weak brick by a suitable rattler test requirement, will make certain, when intelligently enforced, the receipt of a satisfactory, durable, well manufactured, lasting brick paving material.

CHAPTER V

LAYING THE BRICK

THE PLACING OF THE BRICK to form the wearing surface requires the same care and intelligent supervision that has been urged in the construction of the foundation and the selection of the brick. Like the other parts of the pavement, the wearing surface should be designed and constructed of a type most suitable for the street or road on which it is laid. There are a number of different methods of building a pavement surface of brick, each method having some advantages not possessed by the others from the point of view either of cost or service; and that type should be selected which most nearly satisfies the conditions on the street to be paved. Good, serviceable, and durable brick pavements, have been built in a number of different ways, and the type to be selected is therefore no more important than seeing that the workmanship and material in the wearing surface are of the best quality.

Until recent years bricks have always been laid on a layer of sand; before the days of concrete, the sand was laid three or more inches thick and formed the only foundation. After concrete came into use, the sand was still used to bed the brick and was spread over the foundation sometimes as much as three inches in depth and the brick tamped into this. With further developments in concrete mixing machinery, steam rollers, better brick, and a better knowledge of the function of the sand layer, its depth has been gradually reduced to a point where it is just sufficient to level up slight depressions in the foundation and compensate for slight variations in the depth of individual brick. In fact a committee of the American Society of Civil Engineers recently recommended that enough care be used in obtaining a true surface to the concrete base so that the sand layer could be reduced to not less than one half nor more than one inch in depth. It is recognized that a thick layer of loose, mobile material under the brick is the cause of numerous defects in old brick surfaces. Great stress is often laid on the supposition that the sand layer forms a cushion for the brick, protecting them from the blows of traffic. It has been shown by experiment, however, that a layer of sand, which is well compacted and confined has but little more resiliency than the concrete foundation under it. Resiliency to be of any advantage must be of uniform amount throughout the total area and this can only be obtained in a sand layer by thoroughly compacting it. The term sand cushion is a misnomer and sand bed or bedding course should be used for preciseness. The chief function of the sand layer is to provide an adjustable bedding course between the solid concrete and brick so that each individual brick will have a firm, uniform bearing throughout its bedded surface. Any load or blow coming upon the brick will then be distributed over the entire bearing surface and eccentric loads will not cause the brick to tip or deflect if the bed remains firm. It is evident that to perform this function properly, especially where the brick are later bonded together in one solid slab by a cement grout filler, the sand layer should not change in volume, move or shift after the brick have once been firmly bedded. Now the volume of sand increases with its moisture content, and sand as spread on the foundation is frequently moist or dry

in spots. This makes it practically impossible to compress a plain sand layer so that parts of it at least will not shrink to a still smaller volume after the pavement is completed and it has had a chance to dry out. The dry sand is also liable to run or be shaken out of position by the vibration of traffic. At the ends of the pavement, at cracks in the curb or in the foundation, and at other points where it is not confined, the sand will move or shift out of place, and if water should get beneath the brick the sand may be washed out. In repairing cuts made in the pavement it is also difficult to replace the sand layer, which is nearly always disturbed for several feet each

Fig. 24—Preparing the Bedding Course.

way from the opening. These objections are less serious the thinner the layer of sand used, and when proper care is taken with a sand bedding course, an inch or less in thickness, ordinarily no serious difficulty will be experienced. In order to entirely avoid any of these defects, however, and to insure a permanently even, uniform solid bed for the brick, some cities have adopted the practice of mixing Portland cement in the sand layer in the proportions of one part of cement to three or four parts of sand. The mixture is spread dry, the bricks are laid and rolled all in the same manner as when plain sand is used, but before the placing of the filler, enough moisture is added to set the cement by thoroughly sprinkling the brick. This method gives all the advantages of an adjustable bedding course between the

Fig. 25—Laying the Brick (Notice Clamps.)

brick and the concrete foundation, but after the brick have been properly bedded and the cement-sand cushion, as it is called, sets, there is no danger of its shifting, shrinking or moving. Wherever it has been used it has proved very satisfactory. Since the bedding course does not shrink away from the brick, hollow spots do not develop and consequently the rumbling noise of cement-grouted brick is almost entirely eliminated. As the mixture is spread dry, it forms a porous, granular course similar to the ordinary sand layer but with enough cement in it to hold the sand grains in place. The cement in the cement-sand bed does not come into play until after the brick are laid and rolled, so that the method of placing it and laying the brick is the same as where the plain sand bed is used.

The sand for both the plain sand and cement-sand beds should be medium coarse, fairly clean, well graded and sharp, and free from any particles over one quarter of an inch in diameter. A loamy, round grained sand will roll up between the joints in the brick, while with a fine silt sand it is impossible to roll the brick to an even surface.

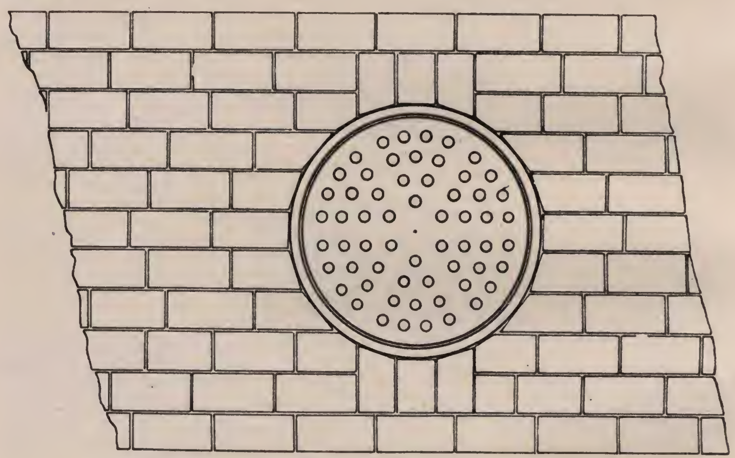


Fig. 26—Turning Brick to Fit Next to Manhole.

The sand or the dry mixture of cement and sand should be spread with shovels to an approximately uniform depth over the smooth concrete base and struck off with a templet similar to the one used for striking the concrete foundation. The ends of the templet rest on the side forms or on wood guide strips one half inch thick placed on the concrete base next to the curb and brought to a true grade and proper height by bedding in a little sand. Where plain sand is used the templet is frequently drawn on double guides which raise it a half inch above the intended final surface of the bedding course. The sand is then rolled with a heavy, long handled hand-roller, depressions filled, and the rolling continued until a true, uniformly compacted surface is secured. The templet is again drawn over the sand, this time with the upper guide strips removed, if double

guides are used, leaving the sand layer ready to receive the brick and true to grade and crown. The brick are then laid directly on this bedding course.

The brick are laid from curb to curb in straight courses and at right angles to the curb with the lug sides all in the same direction. Each alternate course is started with a half brick so that the end joints between courses of brick are broken, and nothing but whole brick are used except at the ends of the courses. The cutting of closure brick must be carefully done and no pieces of brick less than two inches long should be used, a part being cut off of the adjoining whole brick if the closure space is less than two inches. In cutting

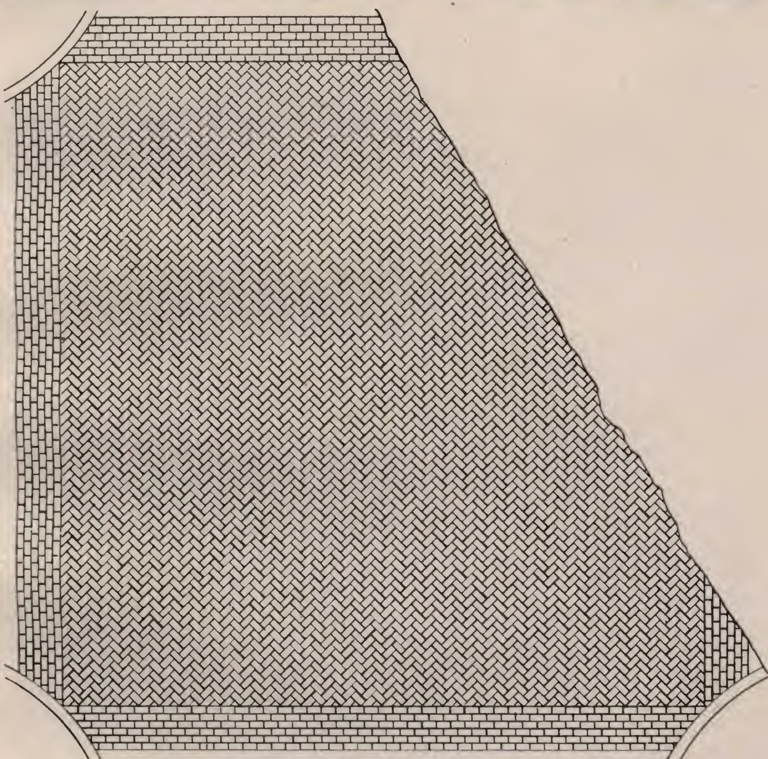


Fig. 27—Heringbone Intersection.

around manholes or valve boxes, care must be taken to avoid slivers or small pieces of brick which will weaken the surface. The method shown in the sketch of turning two or three brick against the manhole cover lengthwise of the street is recommended. The brick should be laid so that the lugs of the brick on one course will touch the brick in the adjoining course and the joints between the ends of the brick should be close and not exceed one eighth of an inch. Frequently one

or more courses of brick next the curb are laid lengthwise of the street and parallel to the curb but there is not much advantage in this arrangement and on narrow roadways where traffic is crowded close to the curb the continuous longitudinal joints may even be detrimental. At intersections where the cross street carries little or no traffic the right-angled courses of brick may be carried across the intersection. It is customary and better practise however to lay the brick so that the wheels of the vehicles crossing the intersection or those turning any of the corners will not have an opportunity to run

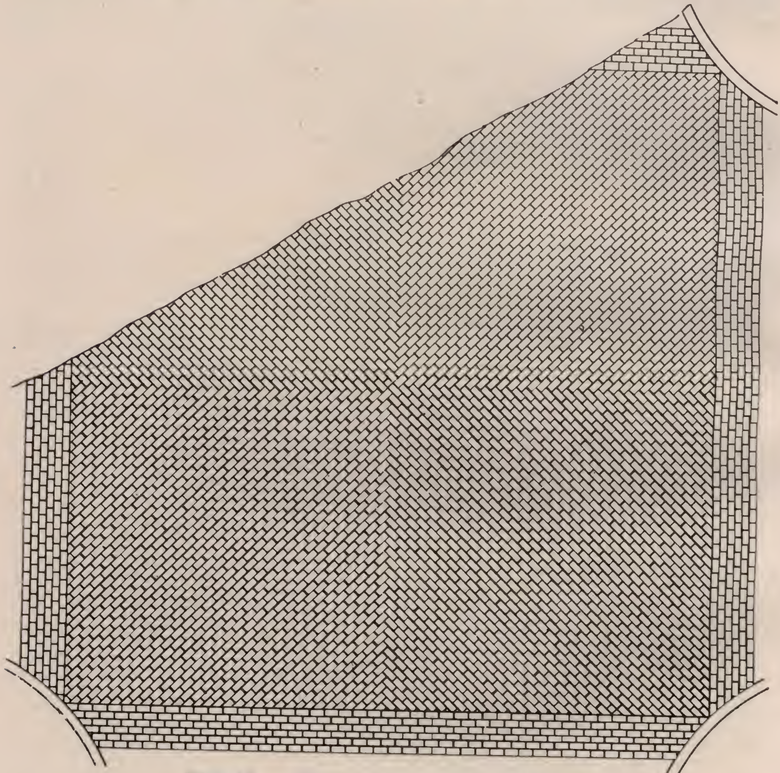


Fig. 28——Double Diagonal Intersection.

in an unbroken joint. The double diagonal method of laying the intersections is probably the best method of accomplishing this although some prefer the herringbone style both of which are shown in the accompanying diagrams.

Care must be exercised in handling the brick both from the car to the street and from the piles to the bricklayers, so that they will not become damaged by chipping. A sharp hard blow on the corner or edge will chip the best brick. The brick should be carefully handled

in loading and unloading and should not be thrown or dumped into piles. They should be carried to the brick layers on pallets, by clamps or on conveyors and not thrown into barrows and dumped on the pavement. This not only prevents the brick from being chipped

Fig. 29—Vertical Fiber Brick Pavement, Wichita, Kas., Viaduct. Rolled and Culled. Ready for Filler.

but avoids disturbing the bricks already laid and increases the efficiency of the bricklayers by placing the brick so that they may be laid with the least effort. The brick setters stand on the surface already laid and place each brick squarely on the bedding course

without disturbing it in any way. This requires some experience and more skill than may be evident at first sight. If an edge or end of a brick is placed on the sand layer first, the sand is disturbed and the brick dces not get an even bed. Shoving or driving the brick into place after they have been laid is apt to push the sand up between the brick and settle one end or side of the brick below the general level. The brick are placed in close contact, in straight rows and closures are made immediately following the laying so that the pavement may be rolled and the joints filled without delay. The brick should first be rolled with a light roller and then with a 3 to 5 ton steam roller. A horse roller ought not to be allowed. The object of the rolling is to bed each brick firmly in the bedding course and to bring the upper surface to the same uniform level. The light roller gives the brick a slight set in the sand so that the first passage of the heavier roller will not have a tendency to tilt or cause them to creep. In order not to cause the sand to shift under the bricks during the rolling, the pavement is first rolled longitudinally beginning on one side and working toward the center, then crossing to the opposite gutter and working toward the center, each part of the pavement receiving a passage of the roller going both backwards and forwards. The brick are further worked down to a uniform bearing and level, by rolling the pavement in both diagonal directions. Places inaccessable to the roller are tamped with a heavy ram or tamp, striking a short piece of plank moved over the surface. During the rolling, the brick which have been broken or chipped by the roller are removed or turned and any depressions or humps which will not roll out are corrected by removing the brick and readjusting the bedding course. When the sand layer has been properly prepared and the rolling thoroughly done, the resulting surface should be true to grade and crown, even in appearance, and with each brick uniformly and solidly bedded so that it will not rock or tilt when it is stepped on. The smoother the surface, the better and more durable is the pavement. It is very important that this portion of the work be carefully inspected and that no joint filler is allowed to be placed until a satisfactory surface is secured. It is frequently required that the surface of the pavement be tested with a ten foot straight edge laid longitudinally and all inequalities exceeding one quarter of an inch be corrected before filling the joints. If cement has been mixed with the sand in the bedding course, the surface of the brick should be thoroughly sprinkled before the joint filler is placed in order to add enough water to set the cement.

Three forms of joint filler for brick pavements have been in common use: sand, Portland Cement, and a Bituminous Cement of tar or asphalt. Sand filler was used on nearly all the early brick streets, hot sand being swept back and forth over the pavement surface until all the joints were filled, leaving a surplus of sand on the pavement to pack into the joints under traffic. About the only thing to recommend a sand filler is its cheapness. It does not furnish a waterproof surface nor protect the edges of the brick from chipping. It washes out of the top of the joints and causes a dirty, noisy pavement.

On a large majority of brick pavements in the past fifteen years Portland Cement and sand, mixed with water to a thin grout, has been used. In many districts cement grout is the only filler used, and it

has proven very satisfactory, when properly handled. Where a plain sand bedding course for the brick and cement grout for the joints are used, care must be taken that the bedding sand does not roll up between the brick more than a quarter or three eighths of an inch. If the bottom of the joint is filled with sand, the homogeneity of the

Fig. 30—Filling the Joints with Portland Cement Grout.

joint filler is destroyed, and a failure of the grout may result. The sand used for the grout should be clean, sharp and medium coarse; fine round grained sand has no place in any pavement. The sand and cement are usually mixed in equal parts and in small batches but proportions as lean as one part cement to two parts sand have been used. Where a small mixing machine is not available, it is

recommended that the batches of grout be mixed in small, tight, rectangular boxes supported on four legs of unequal length so that the floor of the box is inclined and one corner is lower than all the rest. The sand and cement should be mixed dry, water gradually added and the mixture kept constantly agitated by pulling it up toward the high side of the box with a hoe until it attains a uniform consistency like thin cream. It is then taken out by scoop shovels, placed over the brick to be filled, which have just previously been thoroughly sprinkled with water, and rapidly broomed back and forth with fiber push brooms until all joints are full. Because of the weight of the coarse particles of sand and fine particles of cement, there is a constant tendency for the sand to settle out of the liquid mixture followed by the cement, thus separating the ingredients. To avoid this the mixture must be constantly stirred, while being placed on the pavement in small amounts at a time, and must be broomed quickly into the joints. Dumping large quantities of grout onto the pavement and allowing it to flow over the surface and into the joints is a sure way to obtain a poor, irregular job of grouting. The addition of from 5 to 10 per cent by weight of the cement of hydrated lime in the grout mixture also aids very materially in preventing the separation of the ingredients, making a much more plastic and sticky grout.

After making one application of grout over a section of the pavement, and before the first part of the section has been grouted for longer than thirty minutes, the grout box is moved back and a second application is made, this time of a little thicker consistency, to completely fill all the joints up to the top edges of the brick. It is mixed and applied in the same way as before, but is worked back and forth over the joints with rubber lipped squeegees until the joints are full and no surplus remains on the surface of the brick. If there is any further settlement of the grout in the joints another application like the second should be made. A rubber squeegee can be made by clamping a straight piece of heavy rubber between two boards about 4 to 6 inches wide and 15 to 18 inches long, allowing the rubber to project a couple of inches beyond the edge of the boards and fastening a long handle to the boards. The grouting at the end of each day should be fully completed to steel plates inserted between two rows of brick in order to obtain a vertical joint. These plates are withdrawn as soon as the grout has stiffened. After the grout has hardened sufficiently, the surface of the pavement should be covered with an inch or so of sand or dirt and the covering kept wet during the time the cement grout is curing. The curing period should never be less than one week and should preferably last two weeks or even longer in cool, wet weather.

No traffic of any kind should be permitted on the pavement during the curing period. The protective covering is then removed and the pavement is complete. It is seen that the placing of a satisfactory cement grout filler is a task requiring extreme care to insure that each joint is filled for its full depth with a dense, homogeneous cement mortar which is allowed to develop its full strength under favorable conditions for hardening. A poor cement grout is soon little better than a sand filler, while a good one has many advantages to recommend it.

Since the cement filler binds the individual brick into one solid, rigid, continuous slab, some means should be provided for taking care of the expansion and contraction due to changes in temperature. When the brick slab can be confined rigidly on all sides, the expansion can be taken care of by compression stresses in the brick. If the coefficient of expansion of brick is taken at 0.0000040 per degree F., a raise of 100 degrees F. in a confined vitrified brick having a modulus of elasticity of 10,000,000 would develop a confined stress in the brick of 4,000 pounds per square inch or about one fifth of the actual crushing strength of the brick. In a softer brick having a modulus of elasticity of 5,000,000 the confined stress would be 2,000 lbs. per square inch or again about one fifth of the crushing strength of this quality of brick. Accordingly in the best modern practice no allowance is made for longitudinal expansion in a cement grouted brick pavement, the expansion being taken up by compressive strains in the brick and grout. Only a portion of the theoretical strains will probably be realized but the actual strains are undoubtedly proportional to the moduli of elasticity which in turn increase with the hardness and density of the brick. In order to reduce the magnitude of these stresses where cement grout filler is used, therefore, the brick should be restricted to a grade sufficient to take care of the abrasion due to traffic on the street to be paved, and harder brick should be excluded. An inspection of old, cement grouted, brick streets shows the softer, less dense brick have, as a rule, maintained the filler intact, providing at the same time a surface capable of resisting moderate traffic conditions, while the harder and denser brick frequently show a shattered filler and no wear. The existence of these compressive strains also shows the absolute necessity for extreme care in placing and curing cement grout filler. The grout must extend the full depth of the joint or the brick will close together at the bottom causing them to be lifted from their bed, thus disrupting the pavement.

Expansion joints placed at regular intervals across the street have been tried to relieve pavement expansion strains but have not proved successful. The slab between expansion joints expands but in pulling together during contraction the grout breaks away from the brick on account of the tensile strains set up. The cement grout is strong in compression but weak in tension. Several courses of brick each side of the expansion joint are also loosened by traffic and the grout filler soon becomes separated from the brick, and broken up.

The conditions of transverse expansion are somewhat different. Due to the crown of the pavement the slab is a long, slender, curved column and compression stresses of any magnitude would cause the slab to bend still more, raising it off the bedding course and possibly causing longitudinal tensile cracks to form. This accounts in many cases for the rumbling sound of high crowned, grouted brick pavements. Either the sand layer has settled or the slab has been raised off of its bed and acts as a sounding board for passing vehicles. Curbing is not capable of sustaining much pressure. For these reasons a longitudinal expansion joint should be provided along each side of the grouted brick pavement. Since the computed amount of expansion in a brick slab 50 feet wide for a 100 degrees F. rise in temperature is 0.24 inch, half of which may be assumed to be taken at each curb, expansion joints of one half to one inch in width along each curb should be ample. Provision is made for the longitudinal

expansion joints when the brick are being laid by placing a slightly beveled board of the proper thickness and depth next the curb and laying the brick against it. After the brick have been rolled and grouted and the grout has set sufficiently, this board is removed and the space cleaned out and filled with hot asphaltic cement, or some of the numerous prepared expansion joint fillers may be used. These prepared joints come in convenient lengths of a specified width and thickness and can be laid on edge against the curb before laying the brick. In any case, the completed joint to be of value must be equally compressible throughout its length and depth, and pebbles, dirt, sand or grout should not be allowed to get into the joint before pouring the asphalt.

At about the time cement grout came into use as a brick filler, pitch was used to a considerable extent. The old pitch filled streets were not always successful, chiefly because no tests were imposed to determine the suitability of the filler and contractors used whatever they could get the cheapest, from a pitch that was so soft in summer it would run out of the joints and into the gutters, to one which was so hard and brittle in cold weather that it would powder up and chip out of the joints under traffic. At present it is possible to purchase a pitch under the most rigid requirements made especially for brick filler. The tar manufacturers are also recommending that engineers use a softer grade of pitch, mix it when hot with equal parts of hot sand, and run this mixture into the joints. It is claimed that such a mixture will make a tough, pliable, resilient filler at all ordinary street temperatures. Asphaltic cement has more recently come into use as a bituminous filler. This is due to the reduced price of asphalt and to the fact that it can be purchased in any quantity under nearly any test requirements that guarantee its permanence, pliability, toughness and resiliency under all weather conditions. Tar is more adhesive and more liquid when heated but asphaltic cement is much less susceptible to changes of temperature than tar and on account of its toughness and cohesion makes a very satisfactory brick filler.

The asphaltic cement is heated in proper kettles from 350 to 400 degrees F. so that it will flow easily and is flushed over the surface of the brick after they have been laid and rolled. It is worked back and forth with hot iron squeegees until the joints are completely filled. The heating kettle should be equipped with a thermometer so that all the asphalt may be poured at the same temperature and will not be burned by overheating. The brick surface must be clean and dry and the asphalt should preferably be poured in warm weather. Better adhesion between the asphalt and brick is obtained if the filling of the joints follow close behind the rolling, so that the surface of the brick does not become coated with dust or dirt. The hot asphalt from the pouring can should cover all parts of the brick surface and none of the chilled asphalt on the surface of the pavement should be squeegeed over unfilled joints, as it is liable to bridge the joints without filling them. The squeegees are plates of iron ¼ to ½ inch thick, 2 to 4 inches wide and 15 to 18 inches long with the lower edge beveled; the plate being welded to a long, iron shanked, asphalt-rake handle. Several of these should be provided so that one set may be heating in the fire pot of the asphalt kettle while the others are in use. The hot iron keeps the asphalt liquid and allows it to be

Fig. 31—Vertical Fiber Brick Pavement, Dodge City, Kansas. Applying Asphalt Filler.

worked over the joints until they are full leaving but a thin coating on the surface of the brick. Hot, coarse sand should then be scattered over the surface in sufficient quantities to take up the surplus asphalt. This sand layer is much improved by rolling, additional sand being added wherever the asphalt comes to the surface. This form of construction builds up a sand-asphalt carpet from an eighth to a quarter inch thick on the surface of the pavement which allows the joints to become packed full by traffic where settlement occurs and evens up slight inequalities in the surface. Under much traffic it disappears during the first few years, as it is not intended to be wear resisting but is simply an incident to an easy, economical method of filling the joints. The exposed reticular wire-cut surface of the Vertical Fiber type of brick forms an excellent bond with the asphalt, which adheres much better and lasts longer on the surface of this kind of brick. If desired, this carpet can be maintained on residence streets by subsequent applications of heavy asphaltic road oil, whenever necesary, but this is seldom justifiable on account of the maintenance cost. The asphaltic cement used for joint filler should be of the best quality obtainable, and should be tested for permanence, for ductility, viscosity, and susceptibility to temperature. In character and consistency, it should be the equal of the kind used in the best sheet asphalt pavements.

Since each brick is surrounded by a resilient filler, no further provision need be made for expansion and contraction. Traffic can also be allowed over the pavement as soon as the filling of the joints is compelted. Engineers are more or less divided in their opinion as to whether cement grout or asphaltic cement filler is the best for brick pavements, and there have been many wordy controversies by the advocates of each. No doubt there have been failures of both kinds of fillers as well as many good examples of each. There are so many good points about each of these fillers that a few failures due to inexperience, poor material, or careless workmanship ought not to condemn that material for all future work. Both cement grout and asphaltic cement have many advantages as well as some disadvantages, and the engineer should recognize these and use that filler which is best adapted for the conditions of traffic. The advantages of using a cement grout filler may be summed up as follows:

(1) It waterproofs the joints, preventing surface water from reaching the foundation; (2) it adds strength to the pavement, distributing the traffic loads over a large area of foundation, and bridging slight settlements: (3) it is cheap in first cost and the maintenance cost is very low; (4) as long as it fills the joints and remains intact, it protects the edges of the brick from being broken or chipped, thus increasing the service and life of the brick; and (5) it makes a clean, sanitary surface and one easily kept clean. The disadvantages of cement grout as a filler for brick may be itemized as: (1) on busy city streets it is difficult, often impossible to keep traffic off of the completed pavement long enough for the grout to become hard; (2) it is difficult to make openings in the pavement, and more difficult to repair them properly and protect them from traffic for the ten days necessary for the hardening of the grout; (3) cement grout makes a slick pavement and cannot be used on heavy grades for traffic except with a grooved or "hillside" brick; (4) a cement grouted brick pavement laid on a plain sand bed is more noisy than

Fig. 32—A Finished Asphalt Filled Vertical Fiber Brick Pavement, Marion, Iowa.

where a bituminous filler is used; (5) the cement grout binds the individual brick into a solid, rigid slab subject to the strains of expansion and contraction which may shatter brick of weak internal structure or cause unsightly cracks to appear; (6) the cement grout is very difficult to properly mix, place and cure and requires skillful handling and rigid supervision; and (7) once placed it is difficult to correct or repair defective grout filler.

On the other hand the advantages of an asphaltic cement filler may be enumerated as follows: (1) traffic may be turned on the pavement as soon as the filler is in place thus closing the street a minimum length of time; (2) plumber's cuts and other openings in the street can be more easily made and repaired than with a cement grout filler; (3) it is easier on horses feet and the soft joint gives a good foothold on all grades; (4) it can be easily and successfully manipulated on the street and there is no expense of protecting and curing it after it is in place with the attendant possibility of damage by rain, frost or premature traffic; (5) it makes practically a noisless pavement; (6) all troubles from expansion and contraction are done away with; (7) it forms an elastic cushion all around each brick, protecting them from the shock of blows and allows slight adjustments in the position of the brick to care for shrinking or settling of the sand bed, and (8) it provides a flexible waterproof joint, which is easily maintained. The disadvantages of asphalt filler may be summarized as: (1) it is more expensive in first cost and requires more maintenance than a good cement grout filler; (2) under horse and steel tired traffic it does not wear as well or protect the edges of the brick from chipping; (3) it does not distribute the loads over as great an area of base and consequently does not make as strong a pavement as cement grout filler; (4) it is not as easily cleaned and makes a more or less dirty surface the first year after being placed; and (5) the asphalt will pack down and settle into the joints.

No one kind of filler should be used to the exclusion of all others in general paving work. It is seen that the advantages of Portland cement grout filler recommend it for use on country highways, alleys, and on all streets where there is a large percentage of horse-drawn traffic where most of the disadvantages named do not have much weight. On steep grades, on residence or retail business streets, and on streets which are being constantly torn up or where the traffic is mainly automobiles, asphalt makes the most satisfactory joint filler.

With the idea of making asphalt filled brick pavement more serviceable and durable under severe traffic conditions, some cities have recently specified a wire-cut paving block without lugs. The first brick used in pavements had no lugs, and it was not until cement grout filler came into use that any necessity arose for wider joints between the brick. Lugs on paving brick were introduced to make a wide, uniform joint between the rows of brick and so give sufficient body to the grout to insure its strength and allow it to fill the joint completely to the bottom. The joints in any form of block pavement are usually the places where the first signs of wear occur, and in all other block pavements, every effort is made to make the joints as narrow as possible. The closer the blocks are set, the more support they lend one another, the less opportunity there is for broken corners, and the smoother will be the wearing surface. Where asphalt is used as a filler for brick pavement, narrow joints are especially

desirable as the brick material will then receive all the wear leaving the filler to perform the functions of waterproofing the surface and providing a thin elastic cushion for each block. Brick cannot be made true enough to shape nor need they be laid so close together that there is not some space between them which will be penetrated by the hot asphalt. It is probable that even where cement grout filler is used, narrow jointed brick pavement will prove the most satisfactory. The brick material is so much stronger and more capable of resisting the abrasive wear of traffic than the grout, that a brick wearing surface which does not depend on the joint filler will undoubtedly be more durable. The effect of the impact of heavy loads in crossing from one block to another is also considerably lessened, and experience has proven that on account of this fact, a narrow jointed block pavement will wear smoother and give better service than one with wide joints. On heavy traffic streets where the lugless type of brick pavement has been used, the results have more than justified all of these contentions.

The ordinary cement grouted brick pavement presents the anomaly of two superimposed beams, the foundation and the brick slab, separated by a sand or a sand-cement layer having no strength as a beam. The two beams acting separately are not only much weaker than if they were joined together but the interposing of an inert material also lowers their resistance to thermal changes and to impact. It has been shown that the chief function of the cushion layer is to provide a uniform bed or bearing for each individual brick. If, therefore, a satisfactory bed can be provided for each brick, and if the entire brick surface can at the same time be bonded to the base so that the foundation and wearing surface will act as one beam, economy of construction and a stronger pavement will result. The monolithic type of brick pavement accomplishes this by bedding the brick in the soft concrete base, rolling them lightly to an even surface and immediately filling the joints with Portland Cement grout so that the foundation, the brick, and the grout filler set into one solid, well bonded mass. This form of construction had been tried only on small areas until about two years ago, but a piece at Terre Haute, Ind., now twelve years old is reported to be in good condition with no surface defects and showing only such wear as might be normally attributed to heavily concentrated traffic. A satisfactory method of constructing monolithic brick pavement has been devised and in the past two years a considerable amount of it has been laid on country highways and some on city streets. In building country roads twenty feet or less in width, the sub-grade is first roughed out and steel sideforms firmly set at the sides of the pavement with their top true to line and grade. The sub-grade is trimmed, templeted and rolled and a well-mixed, quaking concrete is deposited and leveled by shovels about an inch or two above the top level of the foundation. This concrete is then drawn down to a true even surface by an ingeneously devised templet. The templet consists of a steel I-beam for the forward cutting edge and a steel channel with flanges placed outward for a rear cutting edge, making in fact a double templet. The I-beam and channel are bent to the proper crown of the pavement, are rigidly braced and connected together with a space of two or three feet between them and are supported on the side forms by a frame and rollers which prevent tipping as it is drawn forward. The cutting edge of

Fig. 33—The Double Templeted Foundation for Monolithic Brick Pavements.

the I-beam in front is about a quarter of an inch below the lower edge of the rear channel. In operation the space between the two templets is filled with dry cement and sand mixed in the proportions used for the mortar in the concrete. A forward movement of the templet first cuts off the concrete and then fills all irregularities in the surface with the mortar mixture. The surface thus created is remarkably smooth and is similar in appearance to the ordinary cement-

Fig. 34—Before Grouting Monolithic Brick Pavement (Several Brick removed to show through bedding on the green concrete foundation.)

sand cushion course. In another method, the concrete is drawn by means of a single steel or steel shod templet, sprinkled lightly with a dry-mixed cement and sand and immediately tamped with a "slapstick" or box shaped templet about twelve inches wide until mortar flushes to the surface and the concrete is shaped to a true cross section. The brick are laid immediately on the surface of the concrete

as prepared. If the concrete has been mixed to a quaking consistency but not sloppy, no difficulty is experienced in laying the brick in the usual maner, the bricklayer standing on the brick already in place and having them brought to him on pallets or in clamps. Boards laid on the surface for the carriers to walk on is an additional precaution against displacing any of the brick after laying. With ordinary care there is little trouble in getting a true, even surface to the brick. The brick are then rolled with a sectional hand roller weighing from four to five hundred pounds until all the brick are evenly bedded and the surface is smooth. As soon as possible after the brick are culled but within an hour or so after they have been laid, the joints are filled with Portland Cement grout with the same care and in the same manner as described in this chapter. Concrete work is stopped early enough in the day so that all concrete placed each day may be covered with brick and the whole grouted. The concrete should be spaded and finished against a vertical plank set across the road at the end of the day's work and the brick laid up to this. Where the double steel templet is used the grout is kept back five or six courses from this plank by inserting steel plates between two rows of brick. On beginning work the next day, these last ungrouted courses of brick are removed, allowing room for the rear templet so that the forward templet may cut down the first of the concrete placed.

In paving streets or roads wider than 20 feet, it is difficult to drag the concrete and the luting mixture in one operation and a slightly different method must be used. The concrete is placed and tamped with a heavy templet about a quarter or half an inch below the bottom of the brick course as described in the chapter on foundation. Before this concrete has attained its final set, a cement mortar mixed with enough water to make it work easily is spread over the concrete and dragged to a true uniform surface with a steel templet or a wood templet with a steel plate edge. This mortar coat is luted by hand over intersections or at warps in the pavement where it is not possible to use the templet and the brick are laid, rolled and grouted as on the narrow pavements. The pavement must be covered, protected and cured so that the grout will attain its full strength before traffic is allowed over it, but since the foundation concrete and grout are curing simultaneously, the time which is ordinarily allowed for the concrete to set before laying the brick is saved.

The design and use of a proper templet has made possible the economical construction of a monolithic brick pavement with the result that a solid, rigid masonry pavement slab is obtained with each brick bonded to its neighbors and to the foundation. That such a slab acts as a monolith is proved by recent tests made by the Civil Engineering Department of the University of Illinois. Three slabs were built of wire cut brick, six coures wide and five brick in each course, making the outside dimensions 23 by 45 inches. The first slab consisted of 4 inches of 1-2-4 concrete covered with one eighth inch of 1 to 5 dry mixed sand and cement, with a three inch brick tamped into the green concrete and grouted with a 1 to 1 mixture. Slab two was the same as one except that four inch depth brick was used. Slab three consisted of 4 inch depth brick laid on a one inch base of dry-mixed, one to three cement mortar and grouted with a 1 to 1 mixture. As a check on these slabs a fourth slab of the same

size was made of 1-2-3 concrete 7 inches thick using a good gravel aggregate. All the slabs were allowed to set 24 hours, then covered with sand and kept moist for 27 days, and tested as simple beams of 42 inch span with the load applied at the third points.

TESTS OF MONOLITHIC BRICK SLABS.

Slab No.	Total Thickness	Thickness Base	Thickness Brick	Total Load Lbs	Modus of Rupture Lbs. Per Sq. Inch
1	7-3/16 in.	4-3/16 in.	3 in.	13,100	465
2	8-1/4 in.	4-1/4 in.	4 in.	21,500	580
3	5 in.	1 in.	4 in.	6,700	490
4	7-1/16 in.	7-1/16 in.		12,500	460

The results showed that the brick slabs acted as monoliths and with higher moduli of rupture than plain concrete. The bond between the brick was perfect but some weakness was shown by the eighth inch bedding course of 1 to 5 mortar. It was recommended that this bedding course be made richer and of the same proportions as the mortar for the concrete base.

The chief advantages of the monolithic type of brick pavement construction may be stated as (1) it eliminates the hazard of the sand cushion both during construction and during use, (2) it does away with the necessity of a curbing or edging on country roads, (3) the grout filler remains intact since there is no chance for slight settlements or movement of the brick causing the bond between the brick to be broken, (4) each brick is assured a cement bond for its entire depth even if the mortar works up in the joints slightly during rolling, (5) since the foundation and brick surface act as one unit, thermal effects are cared for without inducing unusual strains in the paving material, (6) there being no chance for shrinkage of the bed, all rumbling of the pavement is eliminated, and (7) the ordinary concrete foundation can be reduced in depth as the brick slab may be depended upon to take its share of the load.

The majority of engineers are of the opinion that the monolithic brick pavement offers wonderful possibilities in permanent highway construction at considerable saving in cost over former methods of construction. It seems probable that a four inch concrete foundation with a two and one half inch or three inch depth brick of this type laid on a well prepared subgrade will be amply strong to withstand the heaviest highway traffic. In resurfacing old macadam roads where the macadam base is satisfactory, the top of the old macadam can be cleaned off, repairs made to the base, depressions leveled up and the surface rolled and watered to a firm, tight condition. An inch or two of rich cement mortar or fine concrete can then be templeted over this old surface and three or four inch depth brick laid. Such a form of construction would be economical and satisfactory, however, only when the old macadam was very close to the proper grade, was of the proper width, and where the base was amply thick and in good condition.

Even when care is taken in the construction of the various types of brick pavements, traffic soon searches out the weak spots in any pavement and slight surface defects may appear. These should be taken care of as soon as they appear, especially all depressions and rough spots should be corrected. Impact is much more

damaging to a pavement than abrasive wear, and if the surface is kept up to grade and smooth, the life of a pavement is very much increased. If a brick pavement is gone over thoroughly in this way after the first or second year it has been down, the cost will be slight

Fig. 35—No Curb Edging Required for Monolithic Brick Paved Highways

depending on the care in construction, and little further repairing will be necessary. Where bituminous joint filler has been used, the joints should be maintained full, additional material being added every three or four years if conditions of traffic demand it. On country roads, ditches should be cleaned out, culverts and drains kept open and the shoulders trimmed and leveled. Broken and soft brick should be removed, cracks filled with hot tar or asphalt, worn brick turned and other needful attention given to the pavement from time to time in

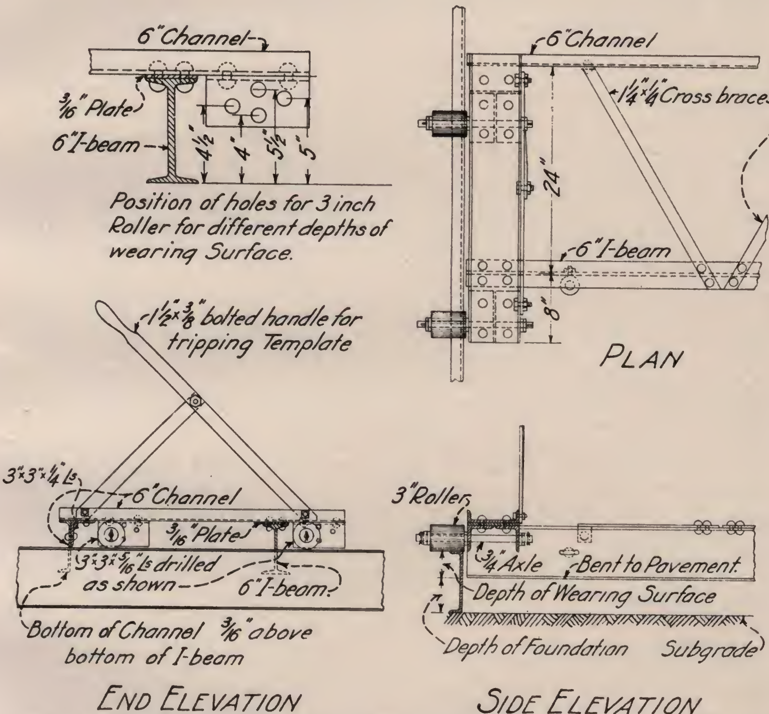


Fig. 36.—Construction of Double Templet Recommended for Building Monolithic Brick Pavements.

order to preserve the original investment in the highest state of efficiency. A well built brick pavement will go longer and wear better without any maintenance than any other kind of pavement, except, possibly granite blocks. It is, however, that much better for having some attention from time to time and the cost is so little as to more than repay in durability alone. For example Mr. H. F. Breed, First Deputy Highway Commissioner of the New York State Highway Department, recently reported that the cost of maintaining 290 miles of brick paved roads of all ages for the year 1915 was $176.00

per mile including some not on concrete foundation. Eliminating these latter, the cost averaged only $131.00 per mile. These figures include cleaning ditches, fixing shoulders maintaining guard rail, patrolling, etc., and he states that the amount spent on the pavement itself was not more than 30 to 40% of this total. In some cases for a series of years there is practically no cost to the brick pavement proper. In comparison he states that the average cost of maintaining, for 1915, gravel roads was $577.00 per mile, waterbound macadam $564.00, bituminous macadam penetration method $448.00, bituminous macadam mixing method $181.00, concrete pavement requiring surface treatment $532.00, and concrete pavement $129.00. Old brick pavements in which the joints have been allowed to deteriorate may often be effectively treated by thoroughly cleaning all loose material from the joints and the surface of the pavement, and when the surface is warm and dry flushing it over with an adhesive, high grade asphalt or tar, absorbing the surplus with a liberal coating of hot sand or stone chips.

A serious problem which is acute in large cities is the constant opening of pavements for underground pipe or conduit connections or extensions. Many attempts have been made to solve this so that no damage will be done to the pavement, but none of them have proved entirely satisfactory or workable. The municipal authorities should have complete control of all openings made in the streets and should see that the backfilling of the trench is properly done. The actual repairing of the pavement should be done by city forces. The old pavement and foundation should be cut back on an upward bevel so that the patch of concrete foundation will have a bearing of at least six inches or undisturbed ground each side of the trench and fit the old foundation like the keystone of an arch. The brick surfacing should be toothed back each way and no bats or broken brick should be left in. The bedding course must be carefully trued and the new brick firmly and evenly bedded, great care being taken that the edges of the patch exactly conform to the old pavement. The filler may then be placed and the patch barricaded until the concrete has attained sufficient strength for traffic. To properly backfill and repair an opening in a pavement is a painstaking and costly task, and the corporation or property owner causing the cut to be made should be compelled to pay the full cost.

Some cities charge the cost of repairs and a fixed sum of $10 to $50 as a penalty for opening the pavement within the first year after it is down. Others serve thirty days notice on all property owners of the city's intention to pave and then refuse all permits, except in a case of emergency for the first year or two after the pavement is completed. There seems to be no way, however, of absolutely preventing the opening and damaging of pavements in cities and the best method of reducing the number and the making of proper repairs must be left to the individual municipality.

From this discussion it is seen that methods of constructing brick pavements as well as the manufacture of material from which they are made, is being constantly improved from the standpoint of economy as well as better service. In fact engineers are of the opinion that the pavements of the future will be constructed of the few standard materials of present day use with a continual improvement in construction methods. Each pavement should be constructed

of the highest type of that kind. Traffic is increasing so enormously even on country roads that any defective material or workmanship, or weak or inadequate pavement construction is soon disclosed. If there is one thing which has been emphasized in this discussion it is that the entire design and construction of the pavement should be carried out to produce uniform strength and uniform wearing qualities. No one ever saw a brick pavement really worn out; they have failed through lack of proper maintenance attention, weak foundation, bad joints, variable quality of brick, wrongful use by traction engines, excessive loads or service cuts.

From past experience and present knowledge, it appears that there are three standard types of brick pavement construction which may be used with the assurance of obtaining a high class and eminently satisfactory surface, namely: first, a bituminous filled narrow jointed brick surface bedded on cement sand and supported by a concrete foundation, second the same type of construction except that the joints are filled with a rich Portland cement grout and third the monolithic construction, the joints being filled, of course, with cement grout. By varying the depth of the foundation to suit the subsoil and traffic conditions and by selecting a depth and quality of paving brick which will best answer the conditions of traffic, the highway engineer can build economical and durable pavements. In drawing his specifications and in supervising the work, he must remember, however, that he is the agent of the contractor as well as of the property owner. On the property owner's side, he should insist on the work and material complying with the requirements of the specifications and see that the specifications contain everything needful to compel a first class piece of work but nothing which adds additional cost without a commensurate increase in the utility of the pavement. For the contractor's sake, the specifications should be complete and clear, containing nothing which it is not expected to enforce, and concisely setting forth all the requirements which must be complied with. Indefinite clauses such as "to the satisfaction of the engineer" should be avoided in any specification as they are almost certain to be a source of trouble and a definite statement of exactly what will satisfy the engineer or will be directed by him should be substituted. A clear understanding of the standard of material and workmanship to be maintained is helpful to all three parties—the property owner, the contractor, and the engineer. The engineer should not seek to cover up his own mistakes by trying to compel the contractor to do more than is required by his contract. On the other hand, in spite of good intentions on the part of the contractor, the work may not prove satisfactory unless each operation is carefully supervised. The laborers and workmen are very liable to become careless and, through lack of proper equipment, organization or knowledge, a poor piece of work may result. A representative of the engineer who understands pavement construction work and knows the requirements of the specifications should be on the job at all times during the progress of the work. He should be a man of broad experience, of good judgment, resourceful and tactful. By encouraging honest, experienced well organized paving contractors, by providing clear well drawn specifications, calling for a properly designed pavement, by securing

dependable inspection, and by playing fair and using good technical judgment himself, the engineer may make an enviable reputation in the building of durable and satisfactory pavements. After all, it is the strict and thoughtful attention given to the minutest details of pavement construction which frequently makes the difference between a first class and a mediocre piece of work.

CHAPTER VI

PAVING PROBLEMS

THE DESIGN AND CONSTRUCTION of pavements has developed under the rapidly increasing severity of traffic into a specialized science calling for a high degree of technical knowledge, a large fund of tact and good judgment, considerable experience, proper organization and thorough supervision. Many problems arise on every job which must be solved to fit particular conditions. The standardization of as many details of paving construction as possible is therefore desirable since it leaves the engineer more time to apply to working out the individual problems of each piece of work. This chapter is therefore devoted to a discussion of some of the general principles of highway design in the hope that what is said may be helpful in solving some of these individual problems in a way which will assure the best service and the most useful and beautiful streets.

A source of much contention is the selection of the type of wearing surface for streets or highways. Enough has already been said condemning the practice of selecting a pavement simply because it is cheap. Neither should a good material be placed at a disadvantage by a general skimping in design in order to reduce the first cost. Cheapness, of course, is a desirable attribute, but must be considered in connection with the life and maintenance cost of the surfacing. For example a medium traffic business street is to be paved, the funds to be provided by the sale of bonds drawing 4 per cent interest and running for ten years, the sinking fund to retire the bonds drawing 3½ per cent interest. If the street is paved with 3 inch Vertical Fiber Brick with an asphalt filler and laid on a 6 inch depth concrete foundation, the computation of the cost per square yard per year over a period of 40 years would be made as follows: Assume the life of the base at 40 years and the life of the brick surfacing at 15 years. The cost of the original pavement is taken at $2.00 per square yard and the cost of renewing the entire surface at $1.40 per square yard. Assume that the street is kept in first class repair at all times and that this cost for the brick pavement will be 2 cents per square yard.

Interest on first bond issue, 0.04x2.00x10..........	$0.8000
Sinking fund first bond issue, 0.08524x2.00x10....	1.7048
Interest on second bond issue, 0.04x1.40x10......	0.5600
Sinking fund second bond issue, 0.08524x1.40x10..	1.1934
Interest on third bond isssue, 0.04x1.40x10x2/3..	0.3733
Sinking fund third bond issue, 0.08524x1.40x10x2/3	.7956
Cost of repairs 0.02x40	.8000
Making a total cost for 40 years................	$6.2271

or cost for one year per square yard $0.1557.

Other types of pavement should be figured in the same way in order to arrive at a decision in regard to the one factor of cheapness. Attention has already been called to the fact

that considerations other than cost, however, are factors in the selection of a suitable pavement. It must be easy to maintain, easy to keep clean, sanitary, have a low tractive resistance and yet not be slippery. It should be acceptable, that is, the personal or local preference must be considered, and it should be favorable to travel, that is, have no bad effects on horses or vehicles using it. All of these characteristics are not equally important and books on paving usually give a table assigning a certain weight to each classification for an ideal pavement. They do not usually recognize, however, that a characteristic which may be extremely important on one class of street, may have little bearing on a different class of street. The qualities which go to make up a satisfactory pavement should therefore be weighted in accordance with the importance of each quality on the particular street to be paved.

The following table gives a suggested arrangement for three classes of highways showing an ideal standard for each type of highway to which it is conceded no pavement can conform. In a parallel column is shown a scoring according to this ideal standard of a type of brick pavement, which most nearly approaches the ideal.

RELATIVE VALUES OF DIFFERENT QUALITIES OF PAVEMENT

	Class "A" Streets		Class "B" Streets		Class "C" Streets	
	Ideal	Brick Grouted	Ideal	Brick Asphalt Filler	Ideal	Brick Monolithic
First Cost	10	8	12	8	15	8
Durability (frequency of repairs)	6	6	8	8	10	10
Maintenance cost . .	20	18	15	15	22	22
Ease of Maintenance	7	7	6	6	9	9
Low Tractive Resistance	15	14	7	6	15	15
Non-slipperiness . .	12	9	10	10	10	8
Sanitation	10	9	15	13	5	5
Noislessness.	7	5	10	9	4	3
Favorableness	5	5	5	5	5	5
Acceptability	8	6	12	10	5	5
	100	87	100	90	100	90

The class "A" street is in a commercial district of a city or town subjected to heavy hauling and mixed traffic; class "B" street is in the built-up residential district but receives some through traffic; class "C" street is a main traveled country road. Other types of pavements or classes of streets can be graded in the same way. For example on the class A street, a grading for a macadam pavement would show the maximum rate for first cost and high values on ease of maintenance, non-slipperiness, and noiselessness; but, on the other hand, it would receive minimum values for durability and maintenance cost, ease of cleaning, sanitation, and acceptability, which would put it out of the running. A granite block pavement would receive high values for durability and ease of maintenance, but would be rated low in first cost on account of its high price and in ease of cleaning, sanitation, noiselessness, and favorableness. To properly apply such a test requires a large fund of technical knowledge and experience,

but in any case such a table is only an aid to the engineer in a selection of the best type of pavement for all the conditions which must be met on any particular street.

The rapid development of modern automobile traffic has introduced conditions which have proved very difficult to meet in pavement design. In the first place, the auto truck brings loads upon the pavement which are many times greater than those of any horse drawn vehicle. Eight and ten ton trucks are becoming common while some trucks approach street car wheel loads in magnitude. The street car load is distributed by heavy steel rails to ties which distribute it through ballast or concrete to a considerable area of subgrade, while the truck is not confined in its travel to any particular street or specially designed portion of the pavement. The actual load on an automobile when regulated as to amount and width of tire, by reasonable laws, is not so serious in itself, as the fact that the load is moving at much greater speed than when drawn by horses. It is evident that a wheel moving at a slow speed will roll into and out of slight depressions or over slight humps, but when a certain horizontal speed is attained, it will drop into the depression or off the hump, the force of impact multiplying the effect of the load depending on the height of the drop. It is the impact effect of these heavy, swiftly moving loads, which is the most destructive to pavements, and makes necessary much more massive foundations in order to absorb the shocks and vibrations and more careful construction than the actual increased weight of the loads would warrant. Every effort must be made therefore to avoid an uneven surface, high manhole covers, valve boxes or rails, and any settlements or depressions which may appear, must be corrected immediately in order to prevent as much as possible the destruction of the adjacent pavement by impact.

The pleasure automobile has revolutionized highway construction and rendered obsolete several types of road construction. An examination of what takes place as an automobile tire moves over the road surface will account for this. In the first place instead of being drawn over the road, an automobile is propelled by forces applied to the rear wheels, the friction between the tire contact surface and the road surface determining the amount of force which can be applied without the wheels slipping enough to simply turn without rolling forward. A very considerable amount of slippage however takes place even when the vehicle is moving, especially when the speed is being accelerated or the brakes are being applied and in addition the tires are constantly exerting a continuous push or pull on the pavement surface. As the portion of the soft rubber tire, which has been in intimate contact with the road, breaks this contact there is a strong suction which also tends to displace the surfacing material.

The pneumatic tire used almost exclusively on pleasure automobiles and on a large percentage of light trucks is approximately circular in cross section, except where it is slightly flattened as it rests on the pavement. Now the outside edges of this flattened portion, (B. Fig. 37) lie on a circumference of less diameter than the center point (A. Fig. 37) and consequently travel at a less lineal velocity since the center point must travel the greatest circumference and therefore at the greatest speed with each revolution of the wheel. Without considering the slippage due to the force on the rear wheels,

there is, therefore, a graduated slipping of the surface of the tires on all the wheels in contact with the road and this slipping increases, the greater the area of contact or the flatter the tire. It is especially destructive to pavements when the tire settles into the surface slightly or runs in a longitudinal depression or rut, since in that case a greater amount of the cross sectional circumference of the tire is in contact with the road surface and the differences in speed of the extreme sides of the tire are greater.

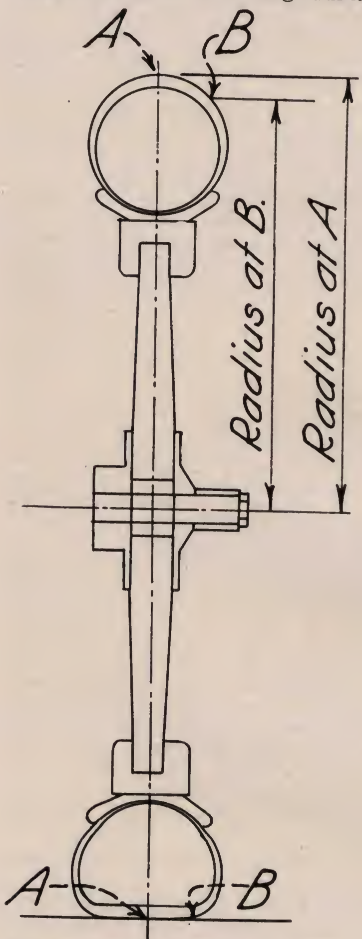


Fig. 37—Slip of Automobile Tires.

These three factors, first the backward push given the road surface by the propelling force on the rear wheels; second the suction of the rubber tire, and third, the tire slippage due both to the driving force and the different lineal velocities of the parts of the tire in contact with the road, have caused the destruction of many highway pavements which gave satisfactory service under horse-drawn, steel tired traffic. Pavements, which are structurally strong and where the cohesion between the particles composing the surface is sufficient to withstand these displacing forces, of course are not affected by the pneumatic tire action. Highway pavements suitable for the traffic of Macadam's day where the particles composing the wearing surface are weakly bound together, are on the other hand rapidly destroyed. Certain other types of pavements show considerable wear and require excessive maintenance especially in the extreme seasons of the year when the cohesion of the surface is likely to be the least.

Street design and especially roadway widths have received considerable attention from engineers recently, and the large number of investigations undertaken have furnished valuable data. It is not proposed to enter the subject of city planning in the brief space of this chapter, but a word in regard to street design may not be out of

place. It seems to be reasonable and economical to establish the widths of paving and sidewalk spaces on city streets to adequately take care of the vehicular and pedestrian traffic which the street in question is expected to develop, but to provide no greater or no less widths. This will require careful study of the amount and kind of traffic, whether or not the traffic is local or there is a single or double street car track, whether the property abutting will be occupied by individual residences, apartment houses, retail business or warehouses, and a number of other factors. It has been found that the average large sized automobile or loaded wagon has a width of 6½ to 7 feet and that an auto truck or transfer wagon with the horses turned at right angles to the wagon, when backed against the curb,

Fig. 38—The Wide Pavement Spoils This Street.

occupies about 14 to 16 feet. Double street car tracks are almost always laid on 10 foot centers, so that including safe clearances a single track car line would require about 11 feet of space and a double car track about 21 feet. Where the vehicular traffic is slow moving the allowable clearance may be less and an 8 foot space is sufficient for each line of vehicles to be provided for, but where speeds of over ten miles per hour are allowed, this should be increased to 9 feet and on boulevards to 10 feet for safety. Cars standing close and parallel to the curb occupy about 6½ feet of space but 9 feet must

be provided to allow for clearance on both sides. When they are allowed to stop at an angle of 30 or 45 degrees to the curb, 9 to 12 feet is taken up and 12 to 15 feet set aside for safety. These figures are average results of a great many actual measurements with liberal allowances for clearances, but do not, of course, take care of extreme cases. These are so unusual, however, that an occasional wide load will not cause any inconvenience on streets where the above spaces are allowed.

Fig. 39—Vertical Fiber Brick Pavement, Garnett, Kansas. A Pleasing Treatment of a Wide Residence Street.

Take for example a retail business street with a double street car track and where automobiles or teams are likely to stand along the curb, the design of the width of the roadway would be as follows:

Double car track	21 feet
Vehicles at an angle along each curb	24 feet
2 lines of vehicular traffic	18 feet
	63 feet

On a semi business street where there is not much vehicular traffic or no provision is made for a line of standing vehicles, the width could be reduced 24 feet, making it 39 feet. Many streets with a double car track have been built with a width of roadway of 36

feet but this should be considered the minimum for that class of street. On a street in the wholesale or warehouse district where the transfer wagons are backed against the curb it may be necessary to provide a width as follows

Line of wagons backed against each curb........	30 feet
Two lines of slow moving traffic................	16 feet
	46 feet

Boulevards ought not to be paved of less width than is sufficient to provide for four lines of swiftly moving automobiles or 40 feet. On the average residence street two lines of traffic of 9 feet each and one standing at the curb of 8 feet, or a total width of 26 feet, should be sufficient for all purposes as this will allow two automobiles to pass opposite a third standing at the curb or one to pass between two standing at opposite curbs. On strictly local residence streets, two lines of traffic width will prove ample or a roadway width of 18 to 20 feet.

The ordinary recommendation for roadway widths is 8 feet for each line of vehicles and 10 feet for each car track. The widths given above are made liberal, however, to provide additional clearance and safety in driving at 10 to 15 miles per hour. It should be noted that these widths obtained by rational design are frequently in odd numbers and not the usual widths found in cities, where pavements are generally a certain proportion of the total width of the street without regard to the usefulness of such roadway. It is clearly not good engineering to provide either inadequate or extravagant roadways. It is very often the case that a pavement 3 or 4 feet narrower than the one laid would serve all the purposes of the wider one, or an additional 3 or 4 feet to a pavement on a busy car line street would provide for two extra lines of traffic. Pavements are expensive to lay and should therefore be only sufficient to provide for traffic needs during the life of the surfacing.

On country roads, the problem is similar except that one track pavements are feasible where the earth shoulders are properly maintained for turnouts while the usual maximum amount of traffic to be provided for is two lines of swiftly moving vehicles. For a single track road the pavement should not be less than 8 feet nor more than 10 or 11 feet. The best width is 10 feet, a narrower pavement requiring more careful driving and a wider one providing more paving than necessary for a single line of moving vehicles. Single track paved roads should be built at one side of the center line as a half of a future double track pavement. The storm water is then taken directly across the pavement and does not flow from the pavement over the earth road which is on only one side, the maintenance of the dirt roadway part is more easily handled and cheaper, and the pavement can be satisfactorily and economically widened when the amount of traffic becomes great enough. A double track road should not be less than 18 feet nor more than 22 feet .

The amount and distribution of pavement crowns, that is the total vertical rise, given the pavement from the gutter to the center of the roadway, is another vexing problem in pavement design. Many formulae have been devised for solving the question of the total amount of crown, most of which have some merit. These formulae

Fig. 40—A Satisfactory Division of Pavement, Tree and Sidewalk Spaces.
(A Vertical Fiber Brick Pavement.)

of course, take account of the kind of pavement and the width of roadway, and some vary the height of crown with the percentage of grade on the street. Some kinds of pavements being smoother and wearing less than others, will shed the water more easily and quickly and consequently need less slope from the center toward the gutter. Pavements which are subject to damage or washing by running water should have a maximum slope so that the water may be carried to the gutter as quickly as possible. Less crown is also needed on hard surface pavements where the longitudinal grade of the street is steep than where it is flat. A formula taking account of all these factors is too complicated for practical use. In order to promote easy riding qualities pavement crowns should be as flat as possible, and it is recommended that a rate of cross fall be selected for each type of smooth hard surface pavement, which will be satisfactory for flat grades and that this cross fall be used irrespective of the longitudinal grade. For cement grouted brick pavements the total crown should be 1/80 to 1/100 of the total width of the pavement, and for asphalt filled brick 1/60 to 1/80. For example a cement grouted brick pavement 40 feet wide would have a crown of 1/80 of 40 feet or 0.5 feet, but if asphalt filled, the crown would be 1/60 of 40 feet or 0.66 feet; these being the maximum crowns of the respective types of pavement. If there is a car track in the street the space between the outside rails should be deducted from the width of the pavement before applying the rule.

Having determined the amount of total crown, the method of distributing this fall between the center of the pavement and the gutter must be worked out. The simplest way of course would be to make each half of the pavement a plane surface, but this is open to the serious objection of forming an ugly ridge in the center and not being easy riding. The usual custom is for the transverse section of the pavement to follow a parabola in form, that is the amount of vertical drop below the center at any point is proportional to the square of the distance from the center. For example the point on the pavement ½ of the distance from the center to the gutter would be the square of ½ or ¼ of the total crown below the center; at ¼ distant from the center the pavement would be 1/16 of the total crown below the center, at ¾ distant it would be 9/16 and so on. The objections to the parabolic form of pavement surface are that it makes the pavement too flat in the central section and too steep on the sides, does not drain well and tends to drive all the traffic toward the center. It is seldom used nowadays in its true form but is more or less modified in its application. A curve which lies between the parabola and the straight line has been found much more practical. This is a hyperbola and is represented by the formula of R. S. Beard.

$$x^2 = \frac{cw^2y\,(m^2-4) - mw^2y^2\,(m-4)}{16\,c^2\,(m-1)} \quad \text{in which}$$

x=horizontal distance from the center,
y=vertical distance from top of crown,
c=total crown of the street,
w=width of pavement between curbs,
$\frac{c}{m}$=the value of "y" at the quarter points.

By selecting values of "m", the shape of the curve may be varied at will. When m = 2, the equation becomes two straight lines, when m = 4, the equation becomes a parabola.

For values between 2 and 4 for "m", the crown curve will be an hyperbola, and it is recommended that the value of 8/3 be used as this gives a very satisfactory crown curve. The formula reduces then to

$$y = \frac{c}{16}\left(-7 + \sqrt{49 + \frac{1920\,X^2}{W^2}}\right)$$

This formula gives a drop of approximately ⅛ of the total crown at a point one quarter of the distance from the center toward the gutter, ⅜ drop at a point one half the distance from the center to the curb, that is at the "quarter point," and is practically a straight line from this point to the gutter. (Fig. 41) Except when templets are to be cut for use on wide streets, it will not be necessary to compute any other points from the formula as the above rule

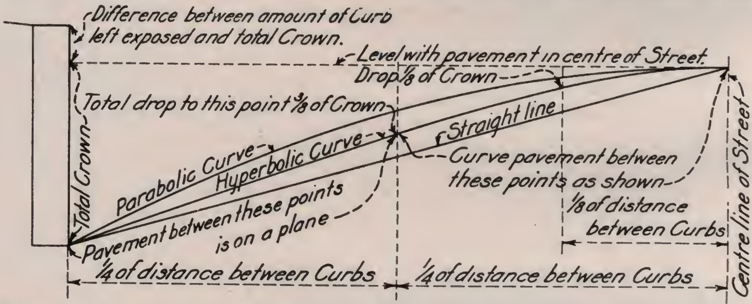


Fig. 41—Comparison of Parabolic and Hyperbolic Crown Curves, with Methods of Laying Out the Latter.

of "⅛, ⅜ and plane" will give a sufficient number of points to finish the pavement. This, however, would only apply where the curbs on opposite sides are level. Where the curbs are at different elevations, the top of the crown curve must be shifted a sufficient distance toward the side of the high curb so that the rise from the low curb does not exceed the maximum allowed for that class of pavement, and then the crown distributed on each side separately as though each side were one half of a distinct street. For example, if a street 40 feet wide is to be paved with brick and the curbs are one foot lower on one side than on the other, the crown could be shifted ten feet off center or 30 feet from the low curb. The maximum permissible crown from the low curb to the top of the crown curve would then be 1/60 of 60 feet, treating the 30 feet toward the low curb as one half of a pavement width, or 1 foot, and the minimum fall from the top of the crown curve toward the high curb would be 1/80 of 20 feet or 1/4 foot, making a difference in the level of the pavement at opposite curbs, 9 inches. Starting with a 4 inch curb face on the low side, 7 inches of curb would therefore show above the pavement on the high side. The 12 inch crown would be distributed in the 30 feet in accordance with the "⅛, ⅜ rule" and in like manner the 3 inch crown in the 10 feet toward the high side. Where the difference in elevation of curbs is too great, it may be

necessary to slope the pavement on a plane from one side of the street to the other. This slope should not exceed a rise of ½ inch vertical to one foot horizontal, the balance of the difference if there is any, being taken up by varying the exposure on the curb. The surface of the pavement should not come higher than 3 inches below the top of the curb and that high only when not much storm water is to be carried; neither should the curb face above the pavement be higher than 12 inches where there is much pedestrian travel. Greater differences must be taken care of by a stepped curb on the high side or what is called double or triple curb. The space between the curb and sidewalk may frequently be terraced to good advantage where there is no necessity for the walk being extended out to the curb. The question of warped pavement surfaces to take care of unusual conditions such as have just been noted and at intersections often requires considerable ingenuity to solve satisfactorily.

The curbing or combined curb and gutter is usually constructed in advance of the paving work, but it is in some ways better and more economical to build the curb at the same time and as a unit with the concrete foundation. The back form for the curbing is substantially set with the top edge true to the line and grade of the top of the curb and after the subgrade has been trimmed the concrete foundation is placed across the street to the proper thickness, the templet for finishing the foundation being supported from the top of the curb forms. After this concrete has begun to set but before it becomes hard, the face form for the curb is set on top of the concrete, spaced and clamped to the rear form and the concrete for the curb poured. Special steel forms are on the market which carry the face form suspended from the rear one so that only one setting is required, and the concrete can be poured almost at one time or the ordinary wooden face board may be suspended by spacers and clamps in the manner shown in Fig. 42. The integral curb makes a stronger, more solid piece of construction and is ordinarily cheaper to build, but requires more careful workmanship and planning in order to insure a satisfactorily looking job.

The radius of curvature of the curbing at the corners depends on the width of pavement, the distance from the curb to the back of the sidewalk and the kind of traffic which the street will accommodate. Narrow pavements should have larger radii on the corner curbs than is necessary for wide pavements, but the radius should not be greater than the width of the sidewalk space on business streets. Too great a radius of curvature encourages fast driving around corners, increases the width of intersection pedestrians must cross and cramps the sidewalk space. On the other hand a sharp radius seriously impedes vehicular traffic and may even cause a dangerous condition at a busy intersection. A radius of 12 to 18 feet is ordinarily sufficient for right angle corners on business or residence streets where pedestrians as well as vehicular traffic must be considered and where the pavement is wide enough for at last three lines of traffic. On residence streets with narrower pavements radii of 20 to 25 feet might be used while on parkways or boulevards accomodating a great deal of motor traffic and with wide parkings radii of 20 to 50 feet are not uncommon, although there is really no

necessity for a radius greater than 30 feet on any right angled corner. Turns in country roads are, however, eased off with much longer curves with a minimum radius of about 50 feet and running as high as 300 feet. The pavement is also usually widened around corners on narrow country highways, and superelevated on the outer edge in proportion to the sharpness of the curves.

Catch basins should never be placed in the center of the radius, two being used if necessary and set back from the corner away from the sidewalk crossing. If this is done the pavement may frequently

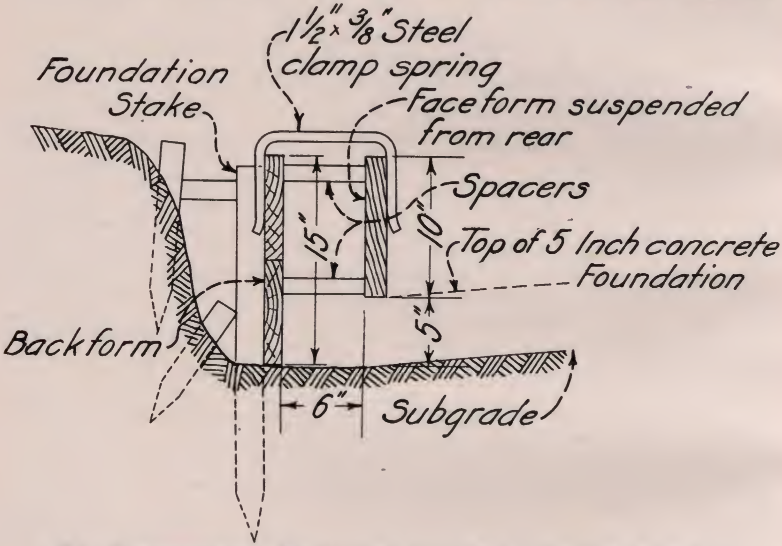


Fig. 42—Suspending Front Curb Form for Combined Curb and Foundation Construction.

be gradually warped up to within 2 or 3 inches of the top of the curb around the radius, draining the water back each way to the side basins and making an easy step for pedestrians crossing the street. It is also a good plan to bring the pavement flush with the top of the curb on alley returns draining the water toward the center by slightly dipping the pavement and thence to the street gutter. This avoids uncomfortable steps in the sidewalk. Where storm water sewers and catch basins have not been constructed, the problem of caring for the surface drainage of the pavements becomes more difficult. Valleys or flat gutters in the pavement surface are frequently used to carry the storm water across intersections. These valleys make the best of a bad situation but even where they are wide and shallow they spoil the easy riding qualities of the pavement. Another method is to carry the water under the intersection in a concrete box or in an open box with castiron cover plates, but these are not usually efficient in heavy storms. Catch basins may also be constructed and drained into a pipe laid under the intersection and behind the curb on the other side to an outlet through the curb and back onto the

pavement. Where the street has a grade of 3 per cent or over this method can be very successfully used and without much additional cost.

The space between the curb and the property line is usually divided except on business streets, into a parking or tree planting space and a sidewalk. If trees are to be planted between the curb and sidewalk a space of at least five feet and preferably seven feet should be provided. If the street is too narrow for this, the trees should be planted between the sidewalk and the property line. Sidewalks ought not to be less than four feet in width as this will allow a person to pass a baby carriage without stepping off the walk. A width of five feet will allow a third person to pass two others walking abreast and is a good average for the majority of residence streets. An 8 foot sidewalk is customarily used on boulevards. In the business section the entire space between the curb and buildings is usually put into sidewalks, and from 8 to 20 foot widths are the most common. Merchants usually object to a greater width than about 20 feet as it throws the vehicular traffic too far from their display windows and of course is not necessary from the pedestrian standpoint. We might, however, learn something from the treatment of some of the wide business streets in Europe, which are frequently lined with trees and where cafe patrons are served under awnings at tables set on the wide sidewalks. It is more difficult to plan the improvements for a street which is much wider than is needed to make ample allowances for present use, than it is to plan a street which is too narrow. American engineers seem to have been particularly devoid of any new ideas in street planning, a subject which offers opportunities for first class engineering work.

On residence streets which have been platted at extravagant widths, ample tree planting space should be provided for one or two rows of trees between the curbing and the sidewalk and the balance of the sidewalk space not occupied by the sidewalk itself thrown into a grass or shrubbery space between the sidewalk and property line. In fact, even on narrrow streets it is a disadvantage to locate the edge of the sidewalk on the property line. Once widths of pavements and sidewalks sufficient to provide for vehicular and pedestrian traffic have been determined upon, the balance of the width of residence streets should be devoted to lawn, shrub and tree planting spaces as these are much more restful and pleasing to the eye than any pavement or sidewalk.

The discussion of the minor details in pavement construction and street planning could be continued at considerable length but it is hoped that enough has been said to show the possibilities of careful street design and construction from both a practical and aesthetic standpoint. The pavement is the utilitarian part of the street and should be constructed in all details in the manner which will best serve at the lowest ultimate cost all the purposes for which it will be used. There is an opportunity along these lines for much improvement in the ordinary American practice.

APPENDIX

STANDARD SPECIFICATIONS FOR VITRIFIED BRICK PAVEMENTS.

THESE specifications, developed by the Western Paving Brick Manufacturers' Association, through a painstaking study of the manufacturing and constructional problems involved, are accurate and comprehensive in their language and stipulations, and are promulgated in the interests of the best and most economical construction of permanent street and road improvements. It is hoped that the general public may profit considerably by this educational effort. Engineers, City Councils, and City or County Commissioners, or others interested in permanent road construction, are invited to use these specifications in whole or in part whenever it appears to their interest to do so. Copies may be obtained gratis by applying to the Secretary of the Association, G. W. Thurston, 416 Dwight Building, Kansas City, Missouri

WESTERN PAVING BRICK MANUFACTURERS ASSOCIATION
WPBMA
PAVE WITH -BRICK-

SPECIFICATIONS

MATERIALS FOR BRICK PAVEMENT

PORTLAND CEMENT. The cement shall be packed in strong cloth or canvas sacks. Each package shall have printed upon it the brand and the name of the manufacturer. Packages received in broken or damaged condition may be rejected or accepted as fractional packages, at the option of the Engineer.

Four (4) bags shall constitute a barrel, and the average net weight of the cement contained in one bag shall not be less than ninety-four (94) pounds, or three hundred and seventy-six (376) pounds net per barrel. The weights of the separate packages shall be uniform.

Cement failing to meet the seven (7) day requirement may be held to await the twenty-eighth (28) day test before rejecting.

Samples shall be taken at random from sound packages, and the cement from each package shall be tested separately. The acceptance or rejection shall be based on the following requirements:

The term "Portland Cement" by the terms of this contract is applied to the product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

The specific gravity of the cement, thoroughly dried at 100 degrees centigrade, shall not be less than 3.10.

It shall leave by weight a residue of not more than 22% on the standard No. 200 sieve.

It shall not develop initial set in less than 45 minutes when the Vicat needle is used, or 60 minutes when the Gillmore needle is used. Final set shall be attained within 10 hours.

The average tensile strength in pounds per square inch of not less than three standard mortar briquettes composed of one part cement and three parts standard sand, by weight, shall be equal to or higher than the following:—

Age.	Strength.
7 days (1 day in moist air, 6 days in water)....	200 lbs.
28 days (1 day in moist air, 27 days in water).........	300 lbs.

The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

Pats of neat cement about three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

They shall then be exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for a period of five (5) hours.

These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

The following limits shall not be exceeded:

Loss on ignition, 4.00%. Insoluble residue 0.85%. Sulfuric Anhydride (SO_3) 2.00%. Magnesia (MgO) 5.00%.

All tests shall be made in accordance with the standards adopted by the American Society for Testing Materials, January 1, 1917.

FINE AGGREGATE. All sand shall be clean and free from lumps of clay, sticks or organic matter, and contain not more than 5% of silt or loam. It shall be passed upon by the Engineer as suitable for the purpose for which it is intended to be used.

Sand for concrete and cement-sand bed shall be sharp and coarse or a mixture of fine and coarse grains with the coarse grains predominating. It shall all pass when dry a screen having 4 meshes to the lineal inch. The sand for the cement grout shall be screened of all sizes retained on a screen having 10 meshes to the lineal inch, uniformly graded and composed of sharp, angular grains. Briquettes made of the sand for concrete or grout in the proportion of one part Portland cement to three parts sand shall not show less tensile strength at 7 and 28 days than briquettes made at the same time with the same cement but using Standard Ottawa sand. Broken stone chips or gravel answering the above specifications may be used as sand if approved by the Engineer.

COARSE AGGREGATE. The broken stone or gravel shall be clean, sound, and durable, free from dust, dirt, shale, rotten or disintegrated rock, or foreign matter. Gravel encrusted with sand grains or dirt will not be allowed. The broken stone or gravel must be screened of all sizes, passing a screen having 4 meshes to the lineal inch and retained on a screen having openings 2 inches in diameter, except that where the concrete foundation is 5 inches or more in thickness, the largest piece shall pass a ring 2½ inches in diameter. It shall grade uniformly from the smallest to the largest size. Flint "chats," is used, shall be screened, clean, coarse, and angular.

DELIVERY OF MATERIAL FOR FOUNDATION. All cement shall be delivered on platforms held at least 6 inches off the ground

and protected by tarpaulins from the elements. Fine and coarse aggregate may be delivered on the rolled subgrade if dry and compact, but in wet weather or where the subgrade is cut up, the Engineer may require them to be delivered on tight plank platforms or on the pavement of intersecting streets.

WATER. The water shall be clean, free from oil, acid, alkali or vegetable matter.

THE BRICK

All brick must be No. 1 pavers of the sizes or types commercially known as "Vertical Fiber Brick," "Repressed Block," "Wire-Cut-Lug Block" or "Brick," whichever kind may be specified for use. They must be thoroughly annealed, tough and durable, regular in size, and evenly burned. When broken, they shall show a dense, stone-like body, free from lime, large air pockets, marked laminations or cracks which would tend to weaken the structure.

The size of Vertical Fiber Brick shall not be less than three and three-quarters (3¾) inches nor more than four and one-half (4½) inches in width excluding lugs, and shall not be less than ....inches* in depth; the size of Repressed Block shall not be less than three (3) inches nor more than three and three-quarter (3¾) inches in width excluding lugs, and not less than four (4) inches in depth; the size of Wire Cut Lug Block shall not be less than three and one-quarter (3¼) inches nor more than three and three-quarter (3¾) inches in width excluding lugs, and not less than..inches* in depth; the size of Brick shall not be less than two (2) inches nor more than two and one-half (2½) inches in width excluding lugs, and not less than four (4) inches in depth.

All brick and block shall not be less than eight (8) inches nor more than nine (9) inches in length. The brick or block from any one plant shall not vary more than one-eighth (⅛) inch in width from the average or standard size of its product, nor more than ⅛ inch in depth from that specified.

If the edges of the brick are rounded, the radius shall not exceed three-sixteenths (3/16) of an inch. Brick laid so that any kiln marks will show on the surface of the finished pavement shall be rejected if the kiln marks exceed one-fourth (¼) of an inch in depth; and at least one edge shall show but slight kiln marks.

*Vertical Fiber Brick may be varied in depth from two and one-half (2½) inches to four (4) inches and Wire-Cut-Lug Block may be varied in depth from three (3) inches to four (4) inches, and the proper depth should be inserted in the blank space.

For light traffic residence streets and for moderate traffic country roads of the monolithic type it is recommended that a 2½ inch depth be used; for business streets in towns and small cities and other streets of moderately heavy traffic and on the main traveled country roads that a three (3) inch depth brick be used; and for heavy traffic business streets in large cities a four (4) inch depth brick be used.

(a) Only brick with raised lugs on one side not to exceed one-quarter (¼) of an inch in height shall be used.*

(b) Only Vertical Fiber Brick without raised lugs shall be used.*

*Either clause (a) or (b) should be crossed out. The lugless type of Vertical Fiber pavement is recommended where asphalt filler is used and an especially smooth even wearing surface is desired. It is slightly more expensive than where lugs are used on account of the greater number of brick per square yard being used.

NOTE: Where the word "brick" is used in these specifications it is intended to refer to Vertical Fiber Brick, Brick Block, Wire-Cut-Lug Block or Brick, whichever may be specified.

RATTLER TEST FOR BRICK

THE CONSTRUCTION OF THE RATTLER

General Design. The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame, and driving mechanism as herein described.

The Barrel. The barrel of the machine shall be made up of the heads, headliners, staves and stave-liners.

The heads may be cast in one piece with the trunnions, which shall be 2½ in. in diameter, and shall have a bearing 6 in. in length, or they may be cast with heavy hubs, which shall be bored out for 2 7/16 in. shafts, and shall be keyseated for two keys, each ½ by ⅜ in. and spaced 90 degrees apart. The shaft shall be a snug fit and when keyed shall be entirely free from lost motion. The distance from the end of the shaft or trunnion to the inside face of the head shall be 15⅜ in. in the head for the driving end of the rattler, and 11⅜ in. for the other head, and the distance from the face of the hubs to the inside face of the heads shall be 5⅛ in.

The heads shall be not less than ¾ in. thick, nor more than ⅞ in. thick. In outline, each head shall be a regular 14-sided polygon inscribed in a circle 28⅜ in. in diameter. Each head shall be provided with flanges not less than ¾ in. thick and extending outward 2½ in. from the inside face of the head to afford a means of fastening the staves. The surface of the flanges of the head shall be smooth and give a true and uniform bearing for the staves. To secure the desired true and uniform bearing the surfaces of the flanges of the head shall be either ground or machined. The flanges shall be slotted on the outer edge, so as to provide for two ¾ in. bolts at each end of each stave, said slots to be 13/16 in. wide and 2¾ in., center to center. Each slot shall be provided with a recess for the bolt head, which shall act to prevent the turning of the same. Between each two slots there shall be a brace ⅜ in. thick, extending down the outward side of the head not less than 2 in.

There shall be for each head a cast-iron headliner 1 in. in thickness and conforming to the outline of the head, but inscribed in a circle 28⅛ in. in diameter. This headliner shall be fastened to the head by seven ⅝ in. cap-screws, through the head from the outside. Whenever these headliners become worn down ½ inch below their initial surface level at any point of their surface, they shall be replaced with new ones. The metal of these headliners shall be hard machinery iron and should contain not less than one per cent of combined carbon.

The staves shall be made of 6-in. medium-steel structural channels, 27¼ in. long and weighing 15.5 lb. per lineal foot. The staves shall have two holes 13/16 in. in diameter, drilled in each end, the center line of the holes being 1 in. from the end and 1⅜ in. either way from the longitudinal center line. The spaces between the staves shall be as uniform as practicable, but shall not exceed 5/16 in.

The interior or flat side of each stave shall be protected by a liner ⅜ in. thick by 5½ in. wide by 19¾ in. long. The liner shall consist of medium-steel plate, and shall be riveted to the channel by three ½ in. rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced 7 in. from the center each way. The rivet holes shall be countersunk on the face of the liner and the rivets shall be driven hot and chipped off flush with the surface of the liners. These liners shall be inspected from time to time, and if found loose shall be at once re-riveted.

Any test at the expiration of which a stave-liner is found detached from the stave or seriously out of position shall be rejected. When a new rattler, in which a complete set of new staves is furnished, is first put into operation, it shall be charged with 400 lb. of shot of the same sizes, and in the same proportions as provided in standard charge, and shall then be run for 18,000 revolutions at the usual prescribed rate of speed. The shot shall then be removed and a standard shot charge inserted, after which the rattler may be charged with brick for a test.

No stave shall be used for more than 70 consecutive tests without renewing its lining. Two of the 14 staves shall be removed and relined at a time in such a way that of each pair, one falls upon one side of the barrel and the other upon the opposite side, and also so that the staves changed shall be consecutive but not contiguous; for example, 1 and 8, 3 and 10, 5 and 12, 7 and 14, 2 and 9, 4 and 11, 6 and 13, etc. to the end that the interior of the barrel at all times shall present the same relative condition of repair. The changes in the staves should be made at the time when the shot charges are being corrected, and the record must show the number of charges run since the last pair of new lined staves was placed in position.

The staves when bolted to the heads shall form a barrel 20 in. long, inside measurement, between headliners. The liners of the staves shall be so placed as to drop between the headliners. The staves shall be bolted tightly to the heads by four ¾-in. bolts, and each bolt shall be provided with a lock nut, and shall be inspected

at not less frequent intervals than every fifth test and all nuts kept tight. A record shall be made after each inspection showing in what condition the bolts were found.

The Frame and Driving Mechanism. The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support it without undue vibration. It shall rest on rigid foundation with or without the interposition of wooden plates, and shall be fastened thereto by bolts at not less than four points.

It shall be driven by gearing whose ratio of driver to driven is not less than one to four. The counter shaft upon which the driving pinion is mounted shall not be less than 1 15/16 in. in diameter, with bearing not less than 6 in. in length. If a belt drive is used the pulley shall not be less than 18 in. in diameter and 6½ in. in face. A belt at least 6 in. in width properly adjusted, to avoid unnecessary slipping, should be used.

The Abrasive Charge. The abrasive charge shall consist of cast-iron spheres of two sizes. When new, the larger spheres shall be 3.75 in. in diameter and shall weigh approximately 7.5 lb. (3.40 kg.) each. Ten spheres of this size shall be used.

These shall be weighed separately after each ten tests, and if the weight of any large sphere falls to 7 lb. (3.175 kg.) it shall be discarded and a new one substituted; provided, however, that all of the large spheres shall not be discarded and substituted by new ones at any single time, and that so far as possible the large spheres shall compose a graduated series in various stages of wear.

When new, the smaller spheres shall be 1.875 in. in diameter and shall weigh approximately 0.95 lb. (0.43 kg.) each. In general, the number of small spheres in a charge shall not fall below 245 nor exceed 260. The collective weight of the large and small spheres shall be as nearly 300 lb. as possible. No small sphere shall be retained in use after it has been worn down so that it will pass a circular hole 1.75 in. in diameter drilled in an iron plate ¼ in. in thickness, or weigh less than 0.75 lb. (0.34 kg.). Further, the small spheres shall be tested, by passing them over the above plate or by weighing, after every ten tests, and any which pass through or fall below the specified weight, shall be replaced by new spheres; provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon	not under	2.50	per cent
Graphitic carbon	" over	0.25	"
Silicon	" "	1.00	"
Manganese	" "	0.50	"
Phosphorus	" "	0.25	"
Sulfur	" "	0.08	"

For each new batch of spheres used, the chemical analysis shall be furnished by the maker or be obtained by the user, before introducing into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

SELECTION OF SAMPLES FOR TESTING. Samples of brick of uniform shape and appearance shall be taken by the Engineer when deemed expedient. Bricks having a defect that would cull them shall not be used.

DELIVERY OF BRICK. The contractor shall notify the proper official of the location and car number of each carload of brick received, so that samples, if deemed necessary and if the brick have not been tested at the plant, may be taken and tested by the Engineer, and no brick shall be delivered on or adjacent to any improvement on which brick are to be used until a written statement has been received from the Engineer or his authorized representative, that they have been superficially inspected or have passed the required tests. Decision relative to each carload will be made within twenty-four (24) hours of notice.

A certificate of acceptance of the brick on the rattler test will not waive the right to reject individual brick on the street which fail to meet the requirements of these specifications, other than the rattler test.

Whenever possible the brick will be tested at the manufacturing plant before loading into cars. When brick are not tested at the plant, any tests desired shall be made before cars are unloaded at destination. When tested from the kiln, samples shall be taken from different locations in the kiln where in the opinion of the engineer or his representative, there is a variation in the quality of the brick, but at least one test shall be made on each 15,000 brick.

NUMBER OF BRICK IN EACH TEST. Ten paving brick shall constitute the number to be used in a single test. The brick shall be thoroughly dried before testing.

THE TEST. The sample of the brick selected for test shall be placed in the rattler hereinbefore described. The rattler shall be rotated at a rate of not less than 29½ not more than 30½ revolutions per minute, and 1,800 revolutions shall constitute the standard test. A counting machine shall be attached to the rattler for counting the revolutions.

A margin of not to exceed ten (10) revolutions will be allowed for stopping. In case a charge is allowed to run several minutes beyond its proper termination, and the loss incurred is still within the prescribed limits, then the test shall not be discarded, but the fact shall be entered on the record.

STOPPING AND STARTING. Only one (1) start and stop per test is regular and acceptable. If from accidental causes a test is stopped and started twice extra, and the loss exceeds the maximum permissible, the test shall be disqualified and another made.

ABRASION LOSS. The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick, any piece weighing less than one (1) pound shall be rejected. The brick shall not lose of their weight more than .... (....%)* per cent when submitted to the above described test.

THE RECORD

DESCRIPTION. The operator shall keep an official book in which the alternate pages are perforated for removal. The records shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed, the original record shall be removed and the carbon duplicate preserved in the book. All calcualtions must be made in the space left for that purpose in the record blank, and the actual figures must appear. The record must bear its serial number and be filled out completely for each test and all data as to dates of inspections, weighing of shot, and replacement of wornout parts must be carefully entered, so that the records remaining in the book constitute a continuous one. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

The blank form for all official brick tests is given on the opposite page.

*Care must be taken in specifying the percentage of abrasion loss to allow for the size of the brick and for brick with square edges like the Vertical Fiber and the Wire-Cut-Lug Brick. A round cornered brick will stand from 2 to 3 per cent better rattler test than a brick of the same size and quality but having square edges. A small sized brick also has a larger proportion of edges to its weight than a larger sized brick and is more likely to be broken in the rattler. The following percentages of loss are recommended for the various classes of brick:

Four inch Vertical Fiber or Wire-Cut-Lug Brick from 22% to 24%.
Three inch Vertical Fiber or Wire-Cut-Lug Brick from 24% to 28%.
Two and one-half inch Vertical Fiber Brick from 27% to 32%.
Four inch Repressed Block from 21% to 24%.
Four inch depth Repressed Brick from 25% to 30%.

REPORT OF STANDARD RATTLER TEST OF PAVING BRICK INDENTIFICATION DATA (Serial No.........)

Name of firm furnishing sample..
Name of the firm manufacturing the sample...
Street or job which sample represents...
Brands or marks on the brick..
Quantity furnished ....
Date received ....Date tested....................................
Length ....Breadth ....Thickness...................

STANDARDIZATION DATA

Number of charges tested since last inspection.....................................
....
....

Weight of Charge. (After Standardization)	Condition of Lock-nuts on Staves	Condition of Scales	Number and Position of Fresh Stave Liners	Repairs. (Note any repairs affecting the condition of the barrel)
Ten Large Spheres............				
.... Small spheres				
... Total weight				

Number of charges tested since stave linings were removed....................
....
....

RUNNING DATA

Time Readings				Revolution Counter Readings	Running Notes, Stops, etc.
	Hours	Minutes	Seconds		
Beginning of Test..............					
Final Reading					

WEIGHTS AND CALCULATIONS

		Percentage Loss (Note: The Calculation Must Appear
Initial weight of ten bricks		
Final weight of same		
Loss of weight		

Number of broken bricks and remarks on same.......................................
....
....

I certify that the foregoing test was made under the specifications of..and is a true record.

Date.................................. Signature of Tester..
Location of Laboratory ....
....

HANDLING OF BRICK. All brick shall be unloaded from wagons or cars by clamps and neatly piled adjacent to the work before the grading is finished. Under no circumstances shall brick be thrown from wagons to piles or from cars to wagons. Brick shall be piled where they will not be spattered with dirt and mud. When laying brick in the pavement, they shall be caried from the piles to the pavers with clamps or on pallets or by suitable conveyors. No wheeling in barrows will be allowed.

ASPHALTIC CEMENT. Where an asphaltic filler for the brick is specified, the asphaltic cement shall conform to the following requirements:

It shall be free from water or decomposition products.

The various hydrocarbons composing it shall be present in homogenous solution, no oily or granular character being present. It must be of such a consistency that at a temperature of 25° C. a No. 2 needle weighted with 100 grams will not, in five (5) seconds, penertate more than 7½ millimeters. The exact penetration shall not vary more than 0.4 millimeters from that fixed by the Engineer for this work within the above limits. The No. 2 needle referred to is a common sewing needle about 1 millimeter in diameter and tapering uniformly to a sharp point for a centimeter of its length.

At 0°C., a No. 2 needle weighted with 200 grams shall penetrate in one minute at least 2 millimeters.

At 45°C., a No. 2 needle weighted with 50 grams shall not penetrate in 5 seconds more than 11 millimeters.

Fifty grams of it shall not lose more than three per cent (3%) in weight upon being maintained at a uniform temperature of 165°C. for five hours in a cylindrical vessel two and three sixteenths (2 3/16) inches in diameter and one and three-eights (1⅜) inches high, and the penetration at 25°C. of the residue must not be less than one-half the penetration of the original sample before heating.

The melting point shall not be less than 80°C. and not more than 120°C.

It shall not contain more than four and one-half per cent (4½%) of carbonaceous matter insoluble in chemically pure carbon bisulphide, air temperature.

It shall be soluble in 85° Baume Petroleum naphtha, air temperature, to the extent of not less than 65% and not more than 85%.

Its solubility in carbon tetrachloride shall not be more than 1½% less than its solubility in carbon bisulphide, both tests being made at air temperature.

Its ductility, at a temperature of 25°C. shall not be less than one centimeter. Ductility by the terms of this contract, shall be understood to mean the distance in centimeters that a cylinder of the asphaltic cement, one centimeter in diameter, can be drawn out at the rate of one centimeter per minute.

The drawing out shall be accomplished by means of two similar clips cylindrical in form, of inside diameter of about three centimeters, open at one end, and having a concentric orific one centimeter in diameter through a circular plate not more than 0.5 millimeters thick and covering the other end. To make a determination, one of the clips is placed on a smooth surface with the open end down. The other clip is then placed on top of the first, with the open end up, so that the one-centimeter orifices coincide. The hot asphaltic cement is poured into the top one slowly so as to fill both clips completely. The temperature of the asphaltic cement is then adjusted to the temperature of 25°C. and the clips are pulled apart at the rate of one centimeter per minute.

EXPANSION JOINT MATERIAL. Where cement grout filler is used for the brick, the expansion joint material shall consist of premoulded asphalt or tar cement held in shape by paper, fiber or wool felt approved by the Engineer.

The paving joint material must be soft and pliable at 32 degrees F. and must not melt or flow at 125 degrees F.

It shall be of the thickness specified and at least 50 per cent shall be pure bitumen. It shall be the full depth of the brick in width and cut into lengths that can be conveniently handled.

CONSTRUCTION OF PAVEMENT

SUB-GRADE

EXCAVATION. The portion of the roadway indicated upon the plans to be paved shall be brought by excavating or filling, as the case may be, from the present surface thereof to a sub-grade which when properly prepared, shall be.......................... (........) inches below the established grade at the curb or gutter line and shall conform to the general cross section of the sub-grade as indicated upon the plans, except at such point or points where there exists a difference in the level between street railway tracks and the curbs, or between the opposite curbs themselves, or where proper drainage may require it, then the surface of the pavement may be lowered or raised within a range of one foot as the Engineer may direct.

Earth in embankment shall be placed in layers not more than six inches in thickness and each layer thoroughly rolled. When the total depth of embankment is one foot or less, the original ground surface, if it is grown to sod, or weeds, or is hard and compacted, shall be plowed so that the added new soil will knit to the old.

No allowance shall be made for any earth placed in embankment except that which is obtained from a source other than the roadway herein provided to be improved and then at the contract price per cubic yard for earth embankment.

EXCAVATED MATERIAL. All cross walks, stone flagging, old paving or guttering, which may be suitable for use by the City, shall be removed by the contractor and deposited uninjured as directed within 1,000 feet of the place of excavation.

Earth or other material excavated in addition to that required for filling on the street being paved shall be used as directed by the engineer for filling and grading adjoining streets or alleys without extra charge, provided that the haul required of such excavated material shall not exceed 1,000 feet.

The contractor shall be paid..............cents per cubic yard for each 100 feet overhaul for distances in excess of 1,000 feet.

All excavated material except as above provided shall be at the disposition of the contractor.

ROLLING. The sub-grade shall be thoroughly rolled with a self-propelled roller weighing not less than two hundred and fifty (250) pounds per inch of face of roller. Should such rolling develop any soft or spongy ground or improperly back-filled excavation for service pipes or connections, etc., the same shall be removed and such excavations and such depressions as may appear shall be refilled and tamped with earth or broken rock acceptable to the

Engineer, and the entire sub-grade be brought to an even and compact surface of uniform bearing power by rolling or ramming. Any damage done to the sub-grade from hauling over it must be repaired before concrete is deposited.

DRAINAGE. At places shown on the plans or where in the opinion of the Engineer, drainage of the sub-grade is necessary, first-class drain tiles shall be laid with open joints on a firm bed to such lines and grades as directed by the Engineer, not less than twelve (12) inches below the finished sub-grade and the trench back-filled with clean cinders or broken stone. The drain shall be connected to the nearest catch basin or other outlet in such manner, as indicated by the Engineer. In general the location of drains will be shown on the plans and these shall be paid for at the price bid, but when during construction it is found necessary to provide drains not shown on the plans for the proper protection of the pavement, the price paid for drain tile, in place complete, shall be the actual labor and material cost, plus ten (10%) per cent, to cover overhead charges, use of tools and profit.

MOISTENING OF SUB-GRADE. When in the opinion of the Engineer, the sub-grade after rolling, is too dry to properly receive the concrete foundation, it shall be thoroughly wet far enough in advance to avoid muddy conditions for placing concrete.

TEMPLET FOR SUB-GRADE. The sub-grade shall be tested by means of the templet hereinafter described to insure the proper grade, crown and depth.

CONCRETE FOUNDATION

THICKNESS OF CONCRETE. Upon the sub-grade prepared as above described, Portland Cement Concrete shall be laid to a thickness after tamping and fininshing of not less than.............. (.........) inches, the upper surface of which shall conform to a plane parallel with and................(........) inches below the finished surface of the pavement.

PROPORTIONS. The Portland Cement Concrete for the foundation shall be composed of one (1) volume of cement, three (3) volumes of sand and six (6) volumes of broken stone or gravel. Measurements shall be by volume of loose materials and one barrel of cement shall be taken as four (4) cubic feet.

Where Flint "chats" are used for the coarse aggregate the proportions shall be one (1) part cement, one and one-half (1½) parts sand and (5) parts screened Flint "chats." The proportions of sand and stone may be varied at the option of the Engineer, but no change will be allowed which will affect the proportions of the cement to the total of the aggregate as specified.

MIXING. The materials for concrete shall be accurately proportioned and mixed in a batch mixing machine of a type approved by the Engineer, and mixing shall continue for at least one-half (½) minute after all materials are in the drum. The drum shall be completely emptied before any material for the following batch is added.

The materials shall be mixed wet enough to produce a concrete of such consistency that it will flush readily when tamped, but which can be handled without causing a separation of the coarse aggregate from the mortar, and which will not creep toward the curb or sag out of place when deposited and lightly tamped. After the addition of water the mixture shall be handled rapidly to the place of final deposit. Under no circumstances shall concrete be used that has begun to set.

Note—It is impossible to write definite specifications for mixing concrete, particularly to fix its proper consistency. At present the best evidence for determining the proper consistency. is found in the nature of the green concrete in place. Certain facts, however, are definitely established.

With any given proportion of the aggregates to cement, the strongest concrete is obtained when the aggregates are uniformly distributed to form a homogeneous mass, with sufficient water to completely hydrate the cement, producing a concrete readily handled and placed.

An excess of water reduces the adhesion of the cement to the fine aggregate, and of the mortar to the coarse aggregate. It also produces a porous concrete. A lack of water prevents hydration or proper setting of the cement, weakens the concrete, and lessens the ease of handling and placing.

DEPOSITING. Immediately prior to placing the concrete, the sub-grade shall be brought to an even compact surface. The concrete must be taken from the machine in such manner as will insure

against loss of mortar, promptly deposited in place and tamped until it has been thoroughly compacted for its full depth and mortar flushes to the surface.

TEMPLET. To assist in bringing the surface of the foundation to correct grade and crown, the Contractor shall furnish a templet extending the full width of the roadway, where the pavement is less than thirty (30) feet wide, and one-half (½) the width of roadway where the pavement is more than thirty (30) feet wide, or there are car tracks on the street. This templet shall be constructed in a manner approved by the Engineer and must be cut so as to fit accurately the upper cross-sectional surface of the foundation as shown on the plans, when the ends of the templet rest on the curb, or on the street car rail. The templet shall be used constantly to insure the proper thickness of concrete is being placed and that the finished surface conforms to the proper grade and crown and is free from depressions and inequalities. The concrete shall be deposited to the full thickness from curb to curb or car track and finished immediately thereafter.

FINISHING. The surface finish of the concrete foundation shall present a reasonably smooth, dense appearance, free from marked uneveness, rock pockets or other defects and true to crown and grade.

CONSTRUCTION JOINTS. When concreting is stopped at noon, at night or for periods of more than thirty minutes, the concrete shall be finished against a plank extending completely across the roadway in a position perpendicular to the surface of the finished pavement. If necessary, in case of a break-down, enough concrete shall be mixed by hand to complete the concrete foundation up to the stop-plank. Any concrete in excess of that necessary to complete the foundation to the stop-plank shall not be used in the work. In any case, great care must be used in tamping and spading the concrete against the stop-plank so that there will be no rock pockets when the plank is removed. When concreting is commenced again, the stop-plank shall be removed and the fresh concrete placed directly against the old concrete. The same care must be taken to avoid rock pockets and to see that the surfaces of the old and new concrete exactly correspond.

HEADERS. Between the curb lines of an intersecting street or alley that is unpaved the concrete and pavement shall be finished against a white oak plank two (2) inches thick and twelve (12) inches deep and of such length as the Engineer may designate. The plank shall be securely spiked to stout oak staves driven well into the ground and backed with sufficient concrete to hold it in place. The upper edge of the plank shall be neatly adzed off to conform to the finished surface of the pavement. Where the work adjoins any pavement already laid, the Engineer may require the contractor to remove and relay a sufficient quantity of the old pavement to form a satisfactory junction of the two pavements.

The concrete shall extend close up to all openings, manholes, catch basins, etc., and be finished about the same in a neat and workmanlike manner.

CURING AND PROTECTING. As soon as the concrete in the foundation has become hard enough to prevent pitting it shall be sprayed with water and shall be kept wet for a period of five (5) days thereafter. This work must be thoroughly done and to the satisfaction of the Engineer. During rainy weather or when the average daily temperature is below fifty (50) degrees Fahrenheit, permission may be obtained from the Engineer to omit the sprinkling.

The contractor shall erect and maintain suitable barricades and provide watchmen to protect the concrete from traffic and any part of the foundation damaged by traffic or other causes during the curing period shall be repaired or replaced in a manner satisfactory to the Engineer.

Under the most favorable conditions for hardening in hot weather, the wearing surface shall not be placed on the foundation for at least seven (7) days and in cool weather for an additional time as required by the Engineer.

Concrete shall not be mixed or deposited when the temperature is below freezing. In no case shall concrete be deposited upon a frozen sub-grade.

CEMENT-SAND BED. Upon the concrete foundation, which has previously been cleaned, there shall be spread a layer of sand and Portland Cement mixed in the proportion of one (1) part cement to four (4) parts sand. The cement and sand shall be mixed dry until the mixture has a uniform color throughout and shall be spread on the foundation dry not less than three-quarters (¾) inch in thickness, the depth being made as nearly uniform as possible and averaging one inch, sufficient to cover all high points or protruding rock in the foundation and provide a uniform bedding course for the brick.

The cement-sand bed shall be carefully shaped to the true cross section of the roadway by means of a properly made templet.

At intersections or where the pavement is to be warped, and a templet is impractical, the use of lutes will be permitted.

The bedding or cushion course shall be prepared at least 20 feet in advance of the bricksetters, but the brick shall be laid, rolled and culled as soon after mixing the dry cement and sand as practical.

THE WEARING SURFACE

LAYING THE BRICK. In delivering the brick from the piles for placement in the streets, no wheeling in barrows will be allowed on the brick surface, but they should be carried on pallets or carriers in such order that when delivered to the dropper, they will lie in such a position, that each brick, in the regular operation of placing it upon the superfoundation as prepared, will bring the projections in the same direction and the better edge uppermost.

For closures nothing less than three (3) inch bats shall be used with the fractured edges laid toward the center of the pavement, a piece being cut off of the adjacent whole brick if necessary to make a three (3) inch closure space. Broken, chipped or warped brick not suitable to lay as a whole shall be used for closures and bats as far as practicable. All joints shall be broken at least three (3) inches. No course shall deviate from a straight line more than two (2) inches in thirty (30) feet. All brick when laid shall be clean and kept clean until the filler is applied. When conditions of the ground are such that mud would be tracked or carried onto the pavement, the work of laying the brick will not be allowed.

ALONG STREET CAR TRACKS. Along street car tracks the brick must not be laid within one-quarter (¼) of an inch of the rail and when rolled shall be one-quarter (¼) of an inch below the top of the rail. The space between the web of the rail and the brick shall be filled with cement mortar made in the proportions of one (1) part Portland Cement and three (3) parts sand. The mortar shall be packed against the rail and cut off to a true surface before the brick are laid.

EXPANSION JOINTS. When Portland Cement grout is specified to be used as a joint filler, expansion joints shall be placed parallel with and at each of the curb lines. The premoulded expansion joint strips of the proper thickness and width shall be set against the curb in advance of the laying of the brick and the brick laid against this, care being taken to have the separate strips close butted and set the full depth of the brick. For roadways less than thirty-six (36) feet in width, the expansion strip along each curb shall be three-quarters (¾) of an inch thick, and for roadways of greater width, one (1) inch in thickness.

ROLLING. After the brick in the pavement have been passed for rolling and the surface swept clean, the pavement shall be rolled with a self-propelled roller weighing not less than three (3) nor more than five (5) tons, in the following manner: The brick next the curb shall be tamped with a hardwood tamper to the proper grade. The rolling shall then commence near the curb at a very slow pace and continue back and forth toward the center until the center of the

street is reached; then passing to the opposite curb, it shall be repeated in the same manner to the center of the street. Each backward passage of the roller shall cover the same path as the corresponding forward passage and each portion of the pavement shall receive enough even passages of the roller to imbed each brick firmly, evenly and to a uniform bearing in the bedding course.

The pavement shall then be rolled transversely at an angle of forty-five (45) degrees from curb to curb, repeating the rolling in the opposite forty-five (45) degree direction. Before and after this transverse rolling has taken place, all broken or injured brick must be taken up and replaced with perfect ones. The substitute brick must be brought to the true surface by tamping.

After final rolling the pavement shall be tested with a six (6) foot straight edge, laid parallel with the curb, and any depressions exceeding one-quarter (¼) of an inch must be taken out. If necessary, the pavement shall be again rolled.

ASPHALT FILLER. Where asphalt filler is specified, the surface of the brick after they have been rolled and culled shall be swept clean, and the filler shall be applied as soon after the rolling as possible. All brick shall be filled and completed on the day on which they are laid.

The asphaltic cement shall be heated in a suitable kettle equipped with a thermometer, which will register the temperature of the contents at all times. The asphaltic cement shall at no time be heated to a greater temperature than its flash point nor poured at a temperature of less than three hundred (300) degrees F. In order to insure that the filler will adhere firmly to the brick they shall be clean and thoroughly dry. The filler shall be moved slowly back and forth over the surface by means of suitable squeegees until all the joints are completely filled and the surface entirly covered with a thin coating. Sufficient time shall be allowed after the asphaltic cement is flushed over the surface before using the squeeges to allow it to penetrate to the bottom of the joints. Care must be taken not to squeegee partially cooled asphaltic cement over uncovered brick thereby bridging the top of the joint and not filling the bottom. All settlement in the joints after the asphalt has cooled shall be corrected by adding filler before placing the top dressing.

A coating of dry, clean "chats" passing a No. 8 screen or sand shall then be uniformly spread over the surface to take up the surplus asphalt. The chats or sand shall preferably be heated to 250 degrees F. The pavement shall then be thoroughly rolled to imbed the surface dressing in the asphalt. After this rolling the pavement may be thrown open to traffic. Additional material shall be added or any surplus swept up and removed as directed by the Engineer any time within ten (10) days after traffic is allowed over the pavement.

CEMENT GROUT FILLER. The filler shall be composed of one and one-half (1½) parts of fine, clean, sharp sand and one (1)

part Portland Cement. The sand shall be measured in a box having the same cubical contents as one sack of cement.

Before any grouting is done, a sufficient amount of cement and the proper amount of sand to complete the work prepared for grouting at that time, but not to exceed one-half (½) day's run shall be thoroughly mixed dry until the mass assumes a uniform color. From this mixture an amount not exceeding two (2) cubic feet shall be taken and placed in the grouting box and water slowly added until a grout that will penetrate to the bottom of the brick is obtained. From the time the water is applied until all is removed and floated into the joints of the pavement the mixture must be kept in constant motion. A mechanical mixer approved by the Engineer that will meet these requirements may be used after the dry mixture of sand and cement has been made. Before the grout is applied the brick shall be thoroughly wet by being gently sprayed.

The water shall be added to this dry mixture in a box preferably about four (4) feet, eight (8) inches long, thirty (30) inches wide, and fourteen (14) inches deep, resting on legs of different lengths, so that the mixture will rapidly flow to the lower corner of the box, the bottom of which shall be about three (3) inches above the pavement. One box shall be used for each fourteen (14) feet in width of roadway, and at least two (2) boxes must be used in all cases.

The grout shall be removed from the box with scoop shovels and applied to the brick in front of the sweepers, who shall rapidly sweep it lengthwise of the brick into the unfilled joints, until the joints are filled to within not more than one-half (½) in. of the top of the brick. After the grout has had a chance to settle into the joint and before the initial set developes, the balance of every joint shall be filled with a thicker grout, and, if necessary, refilled, until the joints remain full to the top.

After this application has had time to settle and before the initial set takes place, the pavement shall be finished to a smooth surface with a squeegee or wooden scraper having a rubber edge, which shall be worked diagonally over the brick.

The contractor must provide thin metal strips about one-sixteenth (1/16) inch by six (6) inches by three (3) feet and insert the same in the brick just across the roadway when closing up a stretch of grouting at work intervals so that the grouting will end in a vertical joint. These strips must be taken out when the grout becomes stiff and before the final set.

When completed and the cement has received its initial set, the pavement shall be covered with a one-half (½) inch layer of sand or loam, which shall be frequently sprinkled in warm weather. No travel shall be permitted on the pavement for a period of at least seven (7) days after grouting, or longer, as the Engineer may require on account of weather conditions.

Ample barricades and watchmen shall be provided by the contractor for the proper protection to the grouting.

MAINTENANCE. During the period for which the pavement is guaranteed by the contractor, he shall maintain in order the grade and surface of all the aforesaid work and make all repairs, which may be necessary from any imperfections in the work or material or from any crumbling or disintegration of the pavement materials. He shall make good to the satisfaction of the Engineer any cracks, bunches, holes or depressions that hold water or that measure more than one-half (½) inch from the underside of a straight edge, six (6) feet long, laid on the surface of the pavement. The contractor shall make good any settlement due to improperly prepared or defective sub-grade, including sunken places on account of any trenches or holes made in the street by any corporation or private party prior to the laying of the pavement.

MONOLITHIC BRICK PAVEMENT

DESCRIPTION. In Monolithic Brick Pavement the cushion or bedding course between the concrete foundation and the brick wearing surface is omitted and the brick are imbedded directly on the fresh unset concrete covered with a cement sand coating. The joints are immediately filled with Portland Cement grout making one solid or monolithic slab of the foundation and wearing surface. Slabs made in this way and tested as a beam show that the two parts of the pavement, the foundation and the brick wearing surface, act as a unit with strength proportional to the total depth of the concrete-brick slab, as is the case in any homogeneous material.

This method of construction has been used most successfully on country highways, although with slight modifications it has been used on wide city streets. The success of the whole construction depends on obtaining an absolutley true, even surface to the concrete foundation so that the brick may be laid while the concrete is fresh and rolled down to a complete and uniform bed and even surface. This is more difficult of accomplishment on many city streets where warps to meet catch basins and special conditions are frequent than on a country road which is commonly uniform in width and crown throughout its length. Since the monolithic brick pavement is stronger for the same depth than the sand cushion method of block pavement construction, the ordinary thickness of foundation and the brick wearing surface may be reduced somewhat. A three (3) inch concrete foundation combined with a good quality two and one-half (2½) inch depth brick should be as strong and satisfactory as a four (4) inch concrete foundation, one (1) inch sand cushion and three (3) inch depth brick. The five and one-half (5½) inch monolithic brick pavement is probably the practical minimum where the pavement is laid on the dirt sub-grade. No curb edging is required on monolithic road paving. All of these items make the pavement construction very economical without detracting from its strength and wearing qualities.

SPECIFICATIONS FOR MONOLITHIC BRICK PAVEMENT

The specifications on the preceding pages for materials to be used in brick pavements should govern where applicable.

The size of the largest piece of coarse aggregate for concrete must, however, not be more than two (2) inches in diameter and should be reduced to one (1) or one and one-half (1½) inches if the foundation is less than four (4) inches in thickness.

The excavation, drainage and preparation of the sub-grade shall be the same as specified for brick pavement. The thinner the foundation used, the greater must be the care in preparing the sub-grade.

The clauses regarding thickness of concrete, proportions and mixing concrete shall be same as specified.

FORMS. Where no curbing is provided, stout forms, preferably of steel, shall be set and securely braced along both sides of the proposed pavement so that the top edge will conform to the line and grade of the top edge of the finished brick pavement, with the bottom on or below the surface of the sub-grade.

DEPOSITING. Immeditely prior to placing the concrete the sub-grade shall be brought to an even compact surface and wet down as heretofore provided. The concrete must be taken from the machine in such manner as will insure against loss of mortar, promptly deposited in place and tamped until it has been thoroughly compacted for its full depth and mortar flushes to the surface.

In placing the concrete, workmen will be guided by a light wood templet resting on the side forms and so made as to leave the concrete a little in excess of the depth required.

Over this shall be drawn a specially constructed steel templet consisting of a six (6) inch I-beam in front and a six (6) inch channel beam in the rear with the flanges turned back, bent true to the crown or cross section of the pavement and placed in a frame so that they will be rigidly held about two (2) feet apart. The templet shall be supported on two (2) rollers at each end resting on the side forms. The first section or I-beam shall be three-sixteenths (3/16) inch lower than the channel beam and cut the concrete base practically to a true surface, which shall be the depth of the brick

to be used below the finished grade of the pavement. In between these beams must be kept a sufficient quantity of dry mixed Portland Cement and sand in the proportions of one (1) part cement to three (3) parts sand. The rear templet distributes this thin coating of dry mortar over the surface of the base leaving the surface entirely smooth. A well built and properly operated templet is one of the essentials of this type of pavement. Any other form of templet which is approved by the Engineer, and will give the surface finish to the concrete required, may be used.

LAYING THE BRICK. Upon the foundation, as prepared, shall be laid the brick before the concrete in it has had an opportunity to set. The brick shall be carried to the brick setters by conveyors, on pallets, or in clamps after first being placed for delivery to the setter, in such order that each brick in the regular operation of placing has the lugs in the same direction with the best face uppermost. The brick setters will stand on the brick already laid, but boards shall preferably be placed for the brick carriers to walk on. Wheeling in barrows over the freshly laid brick will not be allowed.

ROLLING. After the brick in the pavement have been inspected and the surface swept clean, the pavement shall be rolled with a hand roller not less than thirty (30) inches long, made in sections and weighing not less than fifteen (15) nor more than twenty (20) pounds per inch of length. The rolling must be kept close to the laying and continued until the brick are uniformly bedded and the surface is smooth. Portions of the pavement inaccessible to the roller shall be tamped by use of hand tampers applied upon a short piece of plank two (2) inches thick. After the final rolling, the surface shall be tested with a ten (10) foot straight edge, laid parallel to the sides and any depressions or humps exceeding one-quarter (¼) of an inch must be taken out.

The inspector shall keep the brick culled and the contractor shall make the necessary changes and replacements so that the work at all times shall be ready for grouting within twenty-five (25) feet of the brick laying.

CEMENT GROUT FILLER. As soon as the brick have been passed for filling, Portland Cement grout shall be applied and the joints entirely filled as specified under "Brick Pavement."

The pavement will be barricaded and the grout filler cured as specified under "Brick Pavement."

FINISHING DAY'S WORK. The concreting work will be stopped so that all the foundation may be covered with brick and grouted by the end of the day's work. The concrete shall be finished against a vertical stop plank placed transversely to the roadway in the manner specified under "Brick Pavement," and the brick laid, rolled and culled up to this plank. The grouting shall be stopped

five (5) or six (6) rows back from this plank by inserting the metal strips previously described.

On beginning work again, the ungrouted rows of brick will be carefully removed, leaving the foundation bare so that the double steel templet may be backed over it in position for the I-beam to start leveling the first of the fresh concrete placed.

The brick removed will then be carefully replaced in the same positions they formerly occupied, and the laying, rolling and grouting proceed as before.

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